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(NASA-CR-178155) AUTOMATIC BRAKING SYSTEM MODIFICATION FOR THE ADVANCED TRANSPORT OPERATING SYSTEMS (ATOPS) TRANSPORTATION SYSTEMS RESEARCH VEHICLE (TSRV) Final Report (Boeing Commercial Airplane Co.)   N87-13446

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AUTOMATIC BRAKING SYSTEM MODIFICATION
FOR THE ADVANCED TRANSPORT OPERATING
SYSTEMS (ATOPS) TRANSPORTATION
SYSTEMS RESEARCH VEHICLE (TSRV)

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NASA
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Space Administration

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1.0 SUMMARY

Modifications to the 737-100 autobrake system were designed, under NASA Contract NAS1-17635, Task 7. These modifications will enable an on-board flight control computer to control aircraft deceleration to a continuously variable level, for the purpose of executing automatic high speed turn-offs. The design problem and proposed solution are described in this report.

A breadboard version of the proposed modifications was built and tested in simulated stopping conditions. Test results, presented here, show the effectiveness and limitations of the system.

Implementation on the TSRV 737 and flight testing of the proposed design modifications is planned for Phase II of the program.

2.0 INTRODUCTION

The Statement of Work for NASA Contract NAS1-17635, Task 7, calls for modification of the 737-100 autobrake system to allow continuously variable deceleration control, in response to a deceleration command generated in an avionics computer. The purpose of this development is to use the braking system to automatically bring the aircraft to a particular speed, at a particular spot on the runway, to allow automatic, high speed turn offs. It is required that the modifications do not affect the operation of the current 3-level autobrake system or of the anti-skid system. The pilot's ability to override the automatic system, and related safety features must be unaffected. Phase I is an engineering study and modification design.

Control laws for automatic deceleration and turn offs were developed under an earlier NASA Contract (Reference 1). The scheme developed was to use reverse thrust as the main stopping force, and use the braking system for fine closed loop deceleration control. Algorithms to compute the desired reverse thrust level, and the deceleration command signal were presented in Reference 1, and are used here. The deceleration command, at any moment, is just the average deceleration required to bring the aircraft from the current speed to the desired turn speed, in the amount of space available before the turn. The signal is rate limited to provide smoothly varying signals. The desired reverse thrust is computed at the start of the landing rollout, on the premise that the brakes will not be used to slow the aircraft. Aerodynamic drag and tire rolling resistance are accounted for in the computation (presented in Reference 1). The Statement of Work, and the earlier contract work provide the context for this design effort.

3.0 AUTOBRAKE MODIFICATION DESIGN

The design objective is to enable the autobrake system to control deceleration to a continuously variable level. The variable braking system is to be activated when the pilot selects "VARIABLE", with his autobrake control switch, and the Flight Control Computer indicates it is ready to direct the brake system. The Flight Control Computer will provide two signals. The first signal, CV DECEL ON discrete, indicates that the computer is ready to direct the system. The second is an analog signal, which indicates the desired deceleration level.

It is required that the modifications do not affect the operation of the current 3-level autobrake system or of the anti-skid system. The pilot's ability to override the automatic system, and related safety features must be unaffected. If the pilot selects the variable automatic braking system, and the Flight Control Computer is not ready to direct the system, the "AUTOBRAKE INOP" indicator lamp should light.

The design modifications can be grouped into 3 categories. One group pertains to the Aft Flight Deck and its interface with the Forward Flight Deck. A second deals with the autobrake arming and safety logic. The last pertains to the deceleration control loop.

3.1 Background on Current System

Figure 1 is an overall schematic diagram showing only the major components and signals of the autobrake system currently installed in the TSRV aircraft. Figure 2 is a more detailed view showing external wiring of most components. Note that the autobrake control switch is a multi-stage switch. Each stage is part of a separate circuit and has a separate function. One stage, wired to the autobrake circuit breaker, is used to power the autobrake system when the pilot turns it on. Another stage connects the autobrake inoperative light to its control signal. Two more stages (only one is shown in Figure 2, inboard and outboard, are identical) are used to tell the deceleration control cards which setting the pilot has selected.

Figure 3 provides a closer look at the autobrake power circuit. When the pilot moves the autobrake switch to one of the three "ON" positions, (MIN, MED, or MAX), he powers the autobrake system. Power (28 VDC) from the autobrake circuit breaker passes through the brake pedal switches to the automatic brake control module. This box contains logic circuits to check throttle positions, brake pressure levels, air/ground sensing, wheel spinup, etc. It also checks for certain electrical failures. If everything is OK, the automatic brake control module connects 28 VDC to the autobrake valves, and to the "ON RAMP Power" line to the anti-skid module. "ON RAMP Power" activates the deceleration control feedback system. The autobrake valves port full hydraulic system pressure to the anti-skid valves, which control brake pressure.

Deceleration control is accomplished by the "Selected Decel" cards (see Figure 4) in the anti-skid control box. Wheel speed signals from the anti-skid cards are used for sensing, and the control is effected by modulating brake pressure through anti-skid valves. The decel control card generates a reference velocity from the measured wheel speeds and the desired deceleration. The wheel speed error (the difference between the velocity reference and the average of the two wheel speeds) is integrated to generate the control signal, which is sent to the anti-skid valves. Whenever necessary, the anti-skid system can override that signal and reduce brake pressure below the level called for by the deceleration control loop.

The voltage mode on the autobrake card whch represents the desired deceleration (an input to the velocity reference circuit) is controlled through the autobrake control switch (as shown in Figure 4). The pilot sets the switch to MIN, MED, or MAX, which changes the resistor network that determines the deceleration command.

3.2 Autobrake Arming Logic Modifications

Figure 5 is a schematic of the modified autobrake system. The effect of selecting MIN, MED, or MAX is unchanged. Selecting variable decel connects power to one contact of the CV DECEL ON relay. If the relay is turned on by the CV DECEL ON signal from the Flight Control Computer, the autobrake system is powered through the same circuits that currently activate the system. This design retains all of the safety logic built into the automatic brake control module.

To implement the required autobrake inoperative indication, we have designed an additional stage into the autobrake switch. This stage has the wiper grounded and the contact corresponding to the VAR setting connected through the CV DECEL ON relay to the inop light. If variable decel is selected and the relay is not turned on, the lamp will light.

These features can be implemented with minor modifications to the forward flight deck and to the aircraft wiring. Drawing 64-35051 specifies the components replaced and added to the flight deck panel P2-2. A new autobrake control switch is required. The additional relay and diode will be installed behind the panel in a mounting plate added for that purpose. The autobrake control switch wiring is modified slightly. Also, the light plate on the face of the panel is replaced with one showing the new autobrake mode.

The electrical connectors on the panel must be rewired to accommodate three new signals. The CV DECEL ON signal that controls the relay is added, and the two AUTOBRAKE VAR signals are picked up from the anti-skid box.

3.3 Deceleration Control Circuit Modifications

The continuously variable deceleration command is an analog signal picked up from the experimental flight control computer. It is scaled such that 0 volts represents a deceleration of 0 feet/sec/sec, and -10 volts represents 10 feet/sec/sec. An op-amp network was designed to take this signal and produce a deceleration signal compatible with the operation of the deceleration control circuit. Lab tests of the decel control system showed the relationship between the voltage and deceleration. This relationship was used in selecting resistor values for the op-amp network. (It is likely that some adjustment of some of the resistor values will be necessary based on the performance of the system in flight test). If the automatic brake control switch is set to VAR, the op-amp network (see Figure 6) is connected to the velocity reference circuit and sets the deceleration in response to the CV DECEL LEVEL signal generated by the flight control computer. This arrangement preserves the currently available, 3-level autobrake system, but enables the new circuit to take control when required. Note that the deceleration control loop itself is unaffected by these changes to the decel command source.

Modification of the selected deceleration cards and the control box will be carried out by Hydro-Aire Division, Burbank, California, the supplier of the control box.

3.4 Aft Flight Deck and Interface

The autobrake control switch in the aft flight deck is not connected to the braking system. It is connected, through a buffer circuit in the Aft Flight Deck Interface, to the Control and Command Panel in the forward flight deck. The panel includes lights which indicate the setting of the aft flight deck autobrake control switch. The modification design for the aft flight deck and its interface can be summarized as follows:

A. Add VAR setting to the autobrake control switch.

B. Add a channel to the buffer circuit and wiring.

C. Add a light to the Control and Command Panel.

The first task is accomplished by replacing the 4-position switch with a 5-position switch and replacing the light plate that goes with it. The second requires a complete re-design of the buffer circuit. Modification of the current buffer circuit is not feasible because it was built with parts that are no longer available, and because of space constraints on the card. The third task is as simple as it sounds. There are several unused light sockets in the panel.

These modifications are covered in Drawing 64-35052.

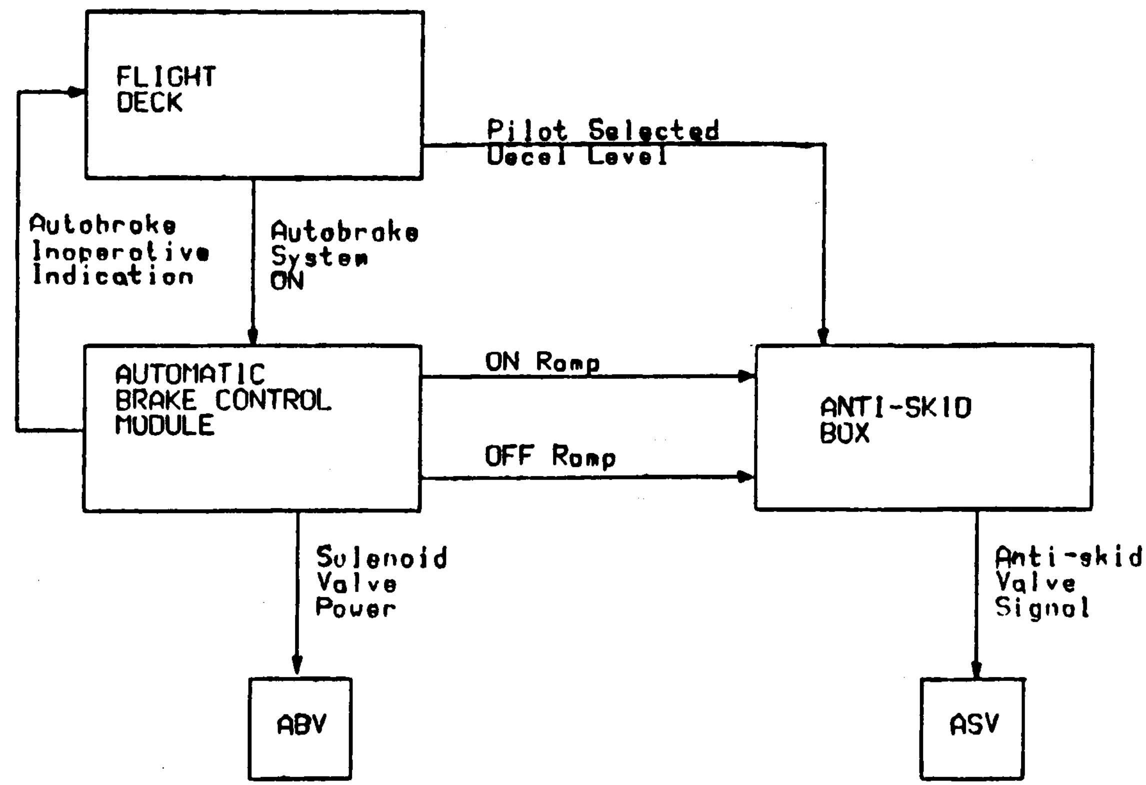


FIGURE 1: AUTOBRAKE SYSTEM OVERVIEW

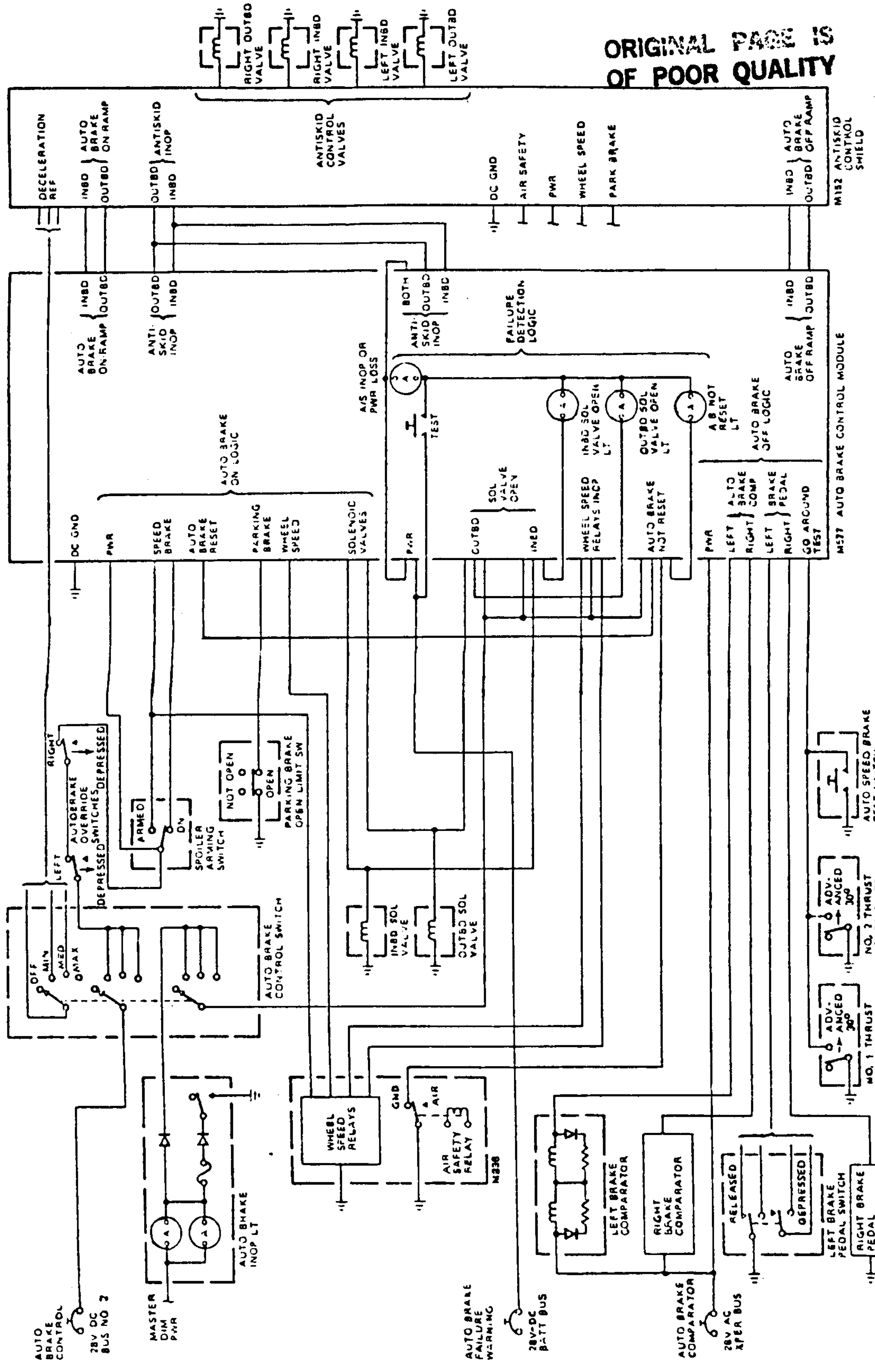


FIGURE 2: ELECTRICAL SCHEMATIC OF CURRENTLY INSTALLED AUTOBRAKE SYSTEM

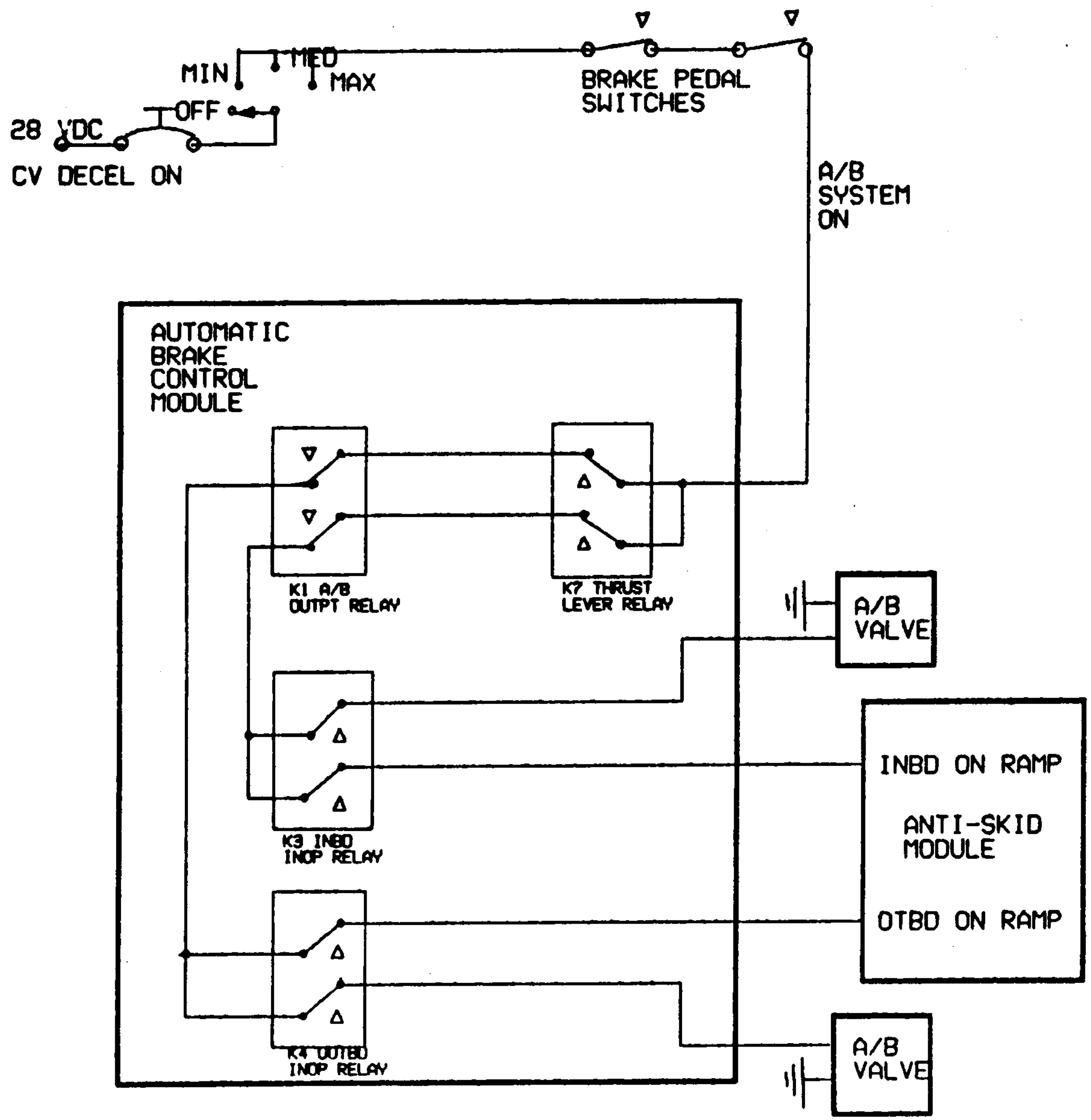


FIGURE 3: CURRENT AUTOBRAKE POWER CIRCUIT

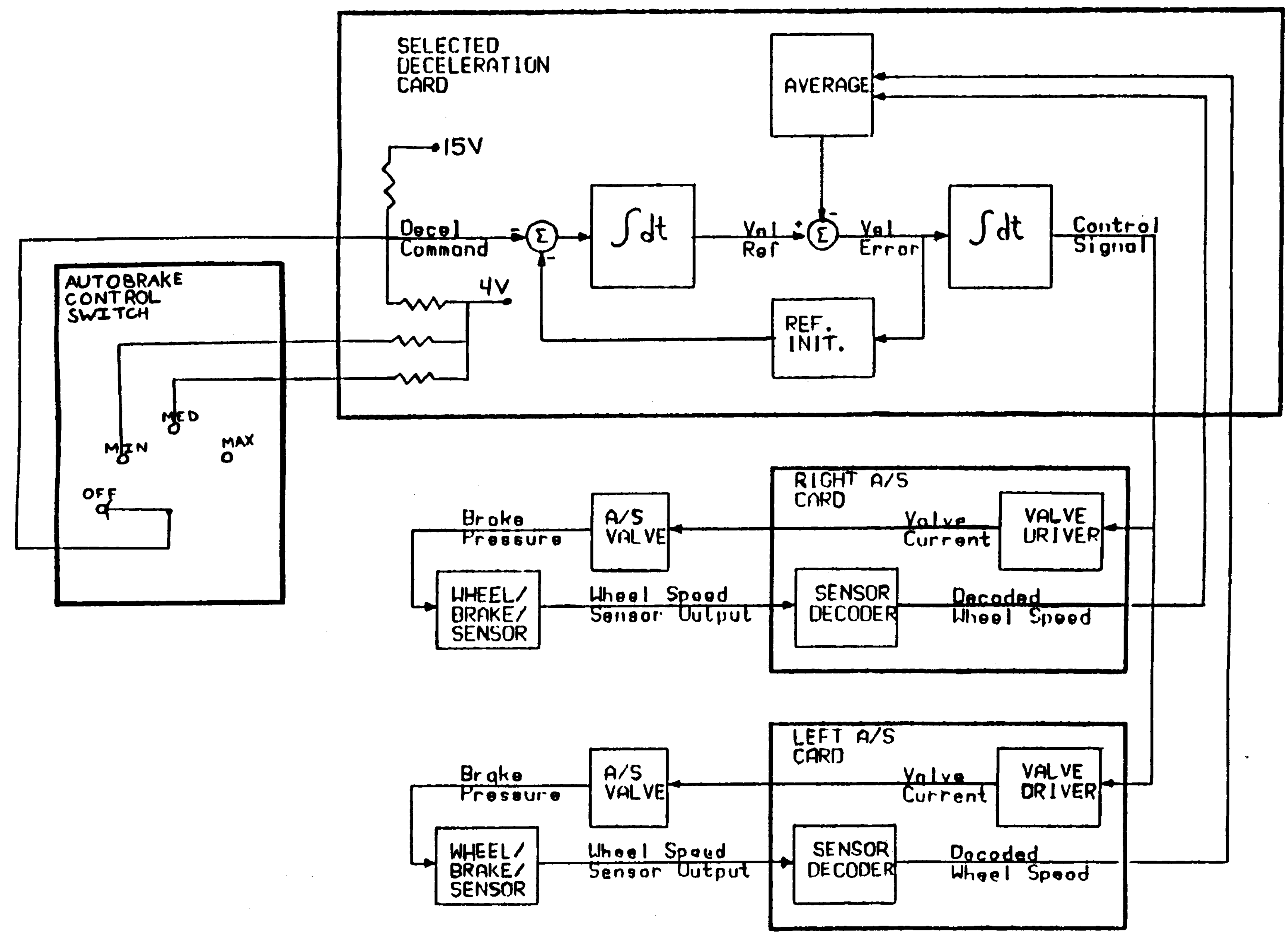
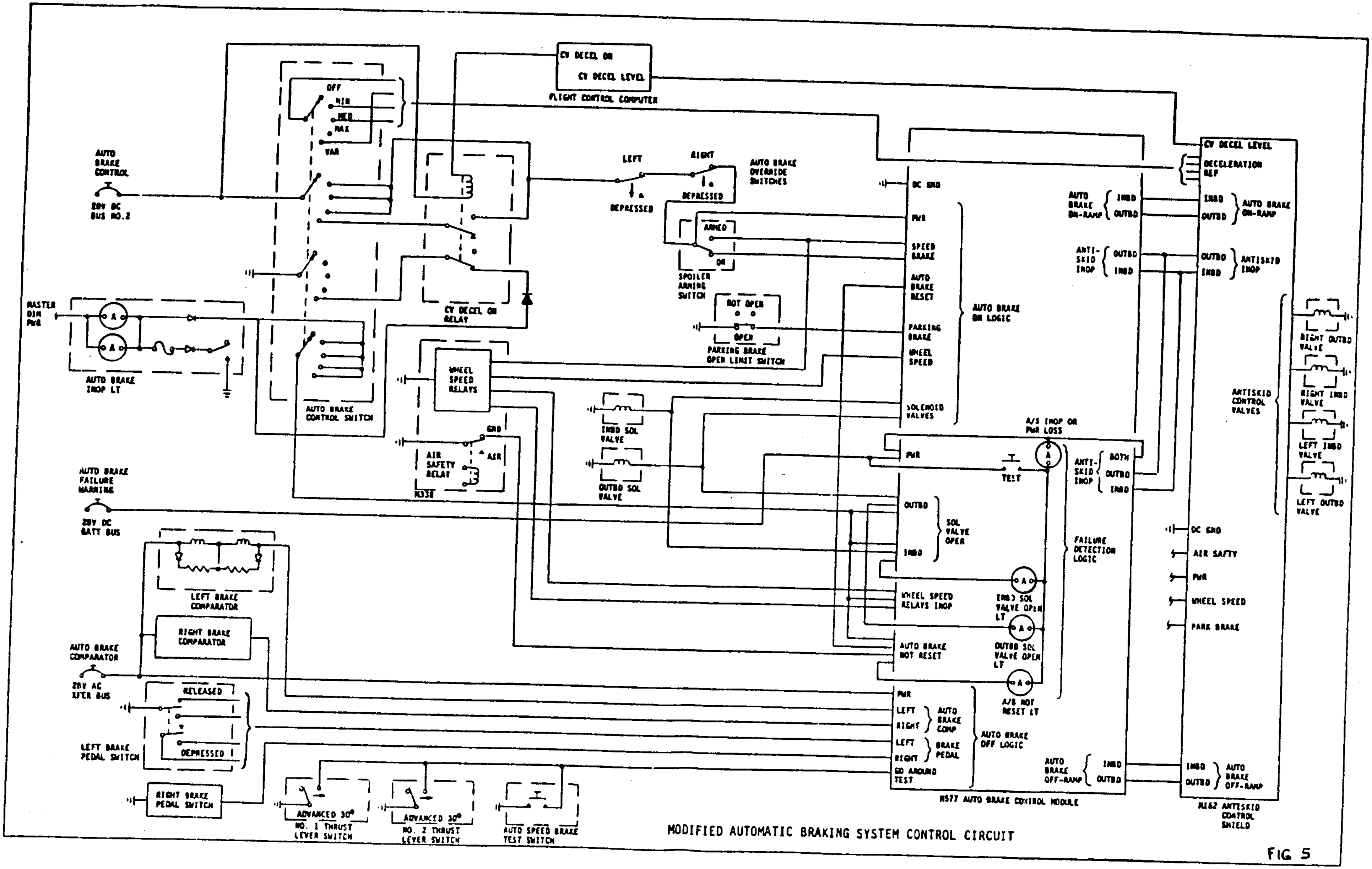


Figure 4: Autobrake Control Loop



MODIFIED AUTOMATIC BRAKING SYSTEM CONTROL CIRCUIT

FIG 5

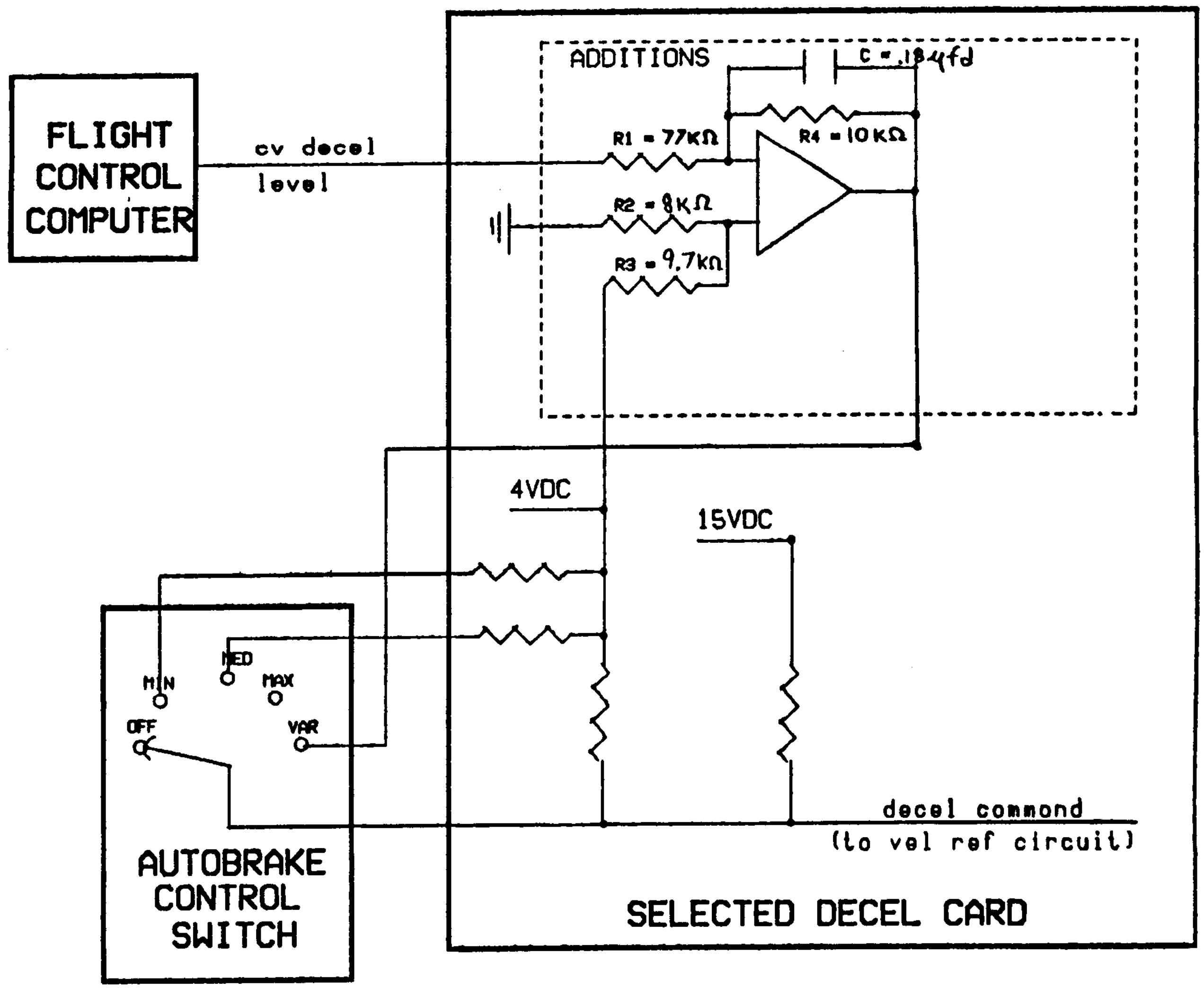


FIGURE 6: MODIFIED DECELERATION COMMAND CIRCUIT

4.0 SIMULATED TEST CONDITIONS AND RESULTS

Performance of the aircraft deceleration control system and the algorithms used to set the reverse thrust command and the deceleration command was tested in a variety of simulated operating conditions. The test results demonstrating the ability of the combined system to achieve a particular speed at a particular location on the runway are presented in this section.

4.1 Test Setup

Testing was carried out in the Hybrid Brake Control Simulated Lab at Boeing. A "triple hybrid" simulation of the TSRV 737 was set up. Actual aircraft hydraulic hardware was used to represent the braking system. An analog computer simulated the high frequency dynamics of the system including fore-aft strut motion, wheel speed dynamics, and the tire-ground interaction. A digital computer was used to simulate the slower frequency aspects of the model, such as gross airplane motion and aerodynamics, and to gather and store data. Figure 7 shows some features of this facility.

This simulated airplane supplied input signals to the modified brake control hardware and responded to its control signals. A 737-100 anti-skid control box was used with 2 MKIII anti-skid cards (right and left inboard wheels), and one deceleration control card (inboard). The addition to the deceleration control card was assembled on a bread-board and patched to the card with clip leads. A "one wheel simulation" was used, meaning the wheel speed dynamics were simulated only once with the result being fed to both anti-skid cards, and the computed ground force scaled up to represent all 4 wheels.

A "breakout box" containing some of the logic circuit was built and connected in as shown in Figure 8. This box housed the autobrake switch, the CV DECEL RELAY, the autobrake inoperative light, and one relay to represent arming logic in the automatic brake control module.

When installed on the airplane, the variable decel control system will receive two electrical signals from the flight control computer. Both were provided in the simulation by the digital computer. The CV DECEL ON discrete could be set from the keyboard or from the simulation control panel. The DECEL LEVEL signal was computed from speed and distance data, as in Reference 1, (according to equation 1) and updated every 10 msec.

$$\dot{U}_{com}(t) = (U(t)-U_{TURN})/2(X_{TURN}-X(t))$$

The following definitions apply:

$\dot{U}_{com}(t)$ = deceleration command.

$U(t)$ = current airplane speed.

U_{TURN} = desired turn speed.

X_{TURN} = distance along runway from arbitrary reference to turn-off.

$X(t)$ = current distance along runway from reference to airplane.

The desired reverse thrust level was computed before the run according to equation 2. This is based on the algorithm used in Reference 1. The factor, k, was included to vary the reverse thrust command from the value called for by the stopping conditions. The command was limited to the maximum available reverse thrust.

$$F_{rev} = \frac{k[(m(U_o - U_{TURN}) + \tau_e F_{IDLE})/t_{roll} - \mu_R W - \rho A_W C_d/6(U_o^2 + U_{TURN}^2 + U_o U_{TURN})]}{2(1-\tau_e/t_{roll})}$$

and

$$t_{roll} = 2X_{TURN}/(U_o + U_{TURN})$$

The variables are defined as follows:

F_{rev} = reverse thrust command per engine.

k = scaling factor used to alter the test conditions.

m = mass of the airplane.

U_o = initial airplane speed.

U_{TURN} = desired turn speed.

τ_e = time constant of engine response.

F_{IDLE} = engine idle thurst per engine.

t_{roll} = expected time from touchdown to the turn.

μ_R = tire rolling resistance factor.

W = airplane weight.

ρ = air density.

A_W = airplane wing reference area.

C_d = drag coefficient.

4.2 Test Conditions

The parameters varied can be considered in three groups. The first group (initial speed, turn speed and distance to the turn) is most important because it defines the average deceleration required. The second group (thrust level and runway mu) has important impact on the ability of the braking system to achieve that deceleration.

A 3-digit case number classification system was assigned to the test matrix as shown in Figure 9. The first digit identifies major classes of conditions. For instance, all the case numbers starting with a 4 identify high gross weight runs. The last two digits identify the combination of initial speed, turn speed, and turn distance. Thus, all the case numbers ending with 06 identify cases with the same combination of speed and distance requirements.

The range of simulated test conditons was based on that of Reference 1. The baseline condition is a 90,000 lb. airplane on a dry runway with no wind, and the thrust command set according to equation 2. The thrust command went from idle to the desired level one second after touchdown, and back to idle when the airplane speed was within 5 feet/sec of the desired turn speed. The response of the engine to this command was modeled as a first order lag with a time constant of 1.3 sec. The initial speed is 200 feet per second (120 knots) and the desired turn speed is 110 feet/sec (65 knots). The distance from touchdown to the turn off is 2300 feet.

To check out a range of required decelerations (runs 001 to 015), initial speed was varied from 110 knots to 135 knots; the range of turn speeds was between 45 knots and 75 knots. Distance to the turn was varied from 1800 feet to 3600 feet, resulting in required of average decelerations from 2.6 to 13.1 feet/sec/sec.

In most cases, the reverse thrust command was set according to equation 1 (as in the baseline case) but in some cases (runs 101 to 106), only half that much thrust was used. These runs give an indication of the impact of inadequate reverse thrust on the accuracy of the system. (Obviously, too much reverse thrust makes it impossible for the braking system to control deceleration). A medium range of speed and distance conditions were run for the low thrust testing.

Most of the conditions were dry runway cases, but a set of wet runway cases were simulated (runs 201 to 206). In these cases, runway friction was computed as a function of airplane speed according to Table 2. A medium range of speed and distance conditions were run for the wet runway testing. In case 304, the friction level was set to .2 for the entire run.

The effect of airplane weight on system performance was investigated for a moderate range of speed and distance conditions. The baseline testing was run at 90000 lb. landing weight. This was varied to 70000 lb. (in runs 504 to 509) and to 110000 lb (in runs 404 to 409). Headwinds and tailwinds of about 15 knots were simulated to evaluate their effect on the deceleration control system. These are the 600 and 700 series runs.

4.3 Test Results

Table 1 in Figure 9 shows the effectiveness of the system in each of the test conditions. The "speed error" tells how close the system came to achieving the desired speed at the turn off. With few exceptions, the error is less than 1 foot/sec.

Time history data for selected cases appears in Figures 10 through 29. The data was plotted by a strip chart recorder connected to the simulator. Two of the recorder channels display multiplexed signals. One channel shows the desired turn speed as a smooth line, compared to the actual airplane speed, which is aircraft deceleration as a smooth curve and the decel command level with the line connected by brief spikes (see Figure 10).

An overview of the time history data shows the following trends. The airplane actual deceleration is usually higher than the commanded deceleration and both decrease with time. The second effect is a result of the first (i.e. if the deceleration exceeds the required level, the required deceleration is reduced). Part of the overshoot is due to a "deceleration transient" at brake application. Another contributing factor is that, for a constant deceleration command setting, deceleration is a function of speed (because of nonlinearity in the wheel speed decoding circuit). In calibrating the system, it was deemed preferable to have excess deceleration at high speed, than to have insufficient deceleration at low speed.

Another prominent feature is that the braking force remains at zero for a substantial portion of most runs. This is because the reverse thrust is providing enough, or more than enough deceleration. The brake system is effectively disengaged and can no longer provide closed loop deceleration control. The deceleration overshoot at brake application and the algorithm used to compute desired reverse thrust combine to cause this condition. The cases in which the reverse thrust command was reduced from the computed value, provide a better indication of the ability of the braking system to control deceleration than the cases in which the brakes are disengaged.

Time history also shows that if often takes about 2 seconds to get the brakes off after the airplane arrives at the desired spot on the runway.

Runs 001 through 015 cover a wide range of speed and distance requirements. Only run 010 shows a large error in speed at the turn off point. In that case, the required deceleration was 13 feet/sec/sec. Since the decel command is limited at 10 feet/sec/sec. and the reverse thrust command is limited to 8200 lb. per engine, the system did not deliver adequate deceleration.

In runs 101 through 106, the commanded reverse thrust was cut by 50% from the computed value. The speed combinations run (see Table 1, Figure 9) required decelerations between 3.9 and 9.6 feet/sec/sec. In every case, the speed error at the turn off was less than 1 foot/sec. Comparison of the brake pressure levels in these runs with those in the previous runs having the same speed and distance combinations, (runs 001 through 006) shows the increased braking effort to compensate for the reduced reverse thrust.

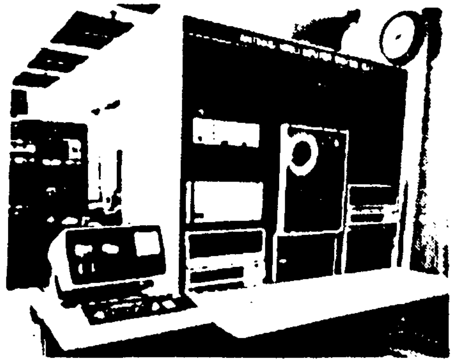
Cases 201 through 304 were run to investigate the system performance on slippery runways. The required decelerations were between 3.9 and 9.6 feet/sec/sec. In only one case was the speed error at the turn off substantially greater than 1 foot/sec. In the other case (run 202 for example), the low friction limited deceleration at high speed, and the anti-skid system controlled the brake pressure. As the runway friction built up, eventually the autobrake system took over and brought the airplane to the desired speed.

In run 204, the high decel case, maximum available reverse thrust was employed, but the wet runway limited the braking force, and the required deceleration was not achieved. Compare this time history data to run 004 (the same speed and distance combination, on a dry runway) and note the braking effort required. Run 304 also had the same speed and distance combinations, and was run with a constant runway mu of .2 (in contrast to the mu versus speed curve used in the other wet runway cases). Run 304 looks just like run 004, indicating that .2 is enough mu, if it is available from the start. Finally, note that near the end of run 204, the system called for and achieved, more deceleration than on the dry runway, but it could not compensate for the low deceleration at high speed.

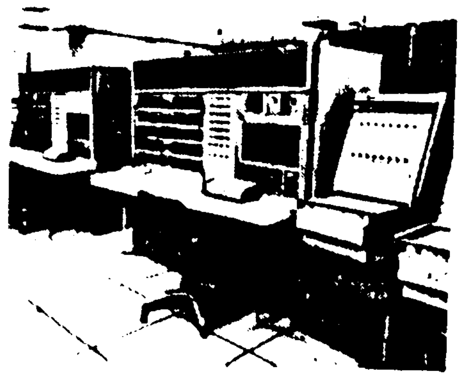
Airplane weight was shown not to affect the system performance. None of the cases run at 70000 lb. or 110000 lb. resulted in speed errors of significantly more than 1 foot/sec. at the turn off. Speed and distance combinations requiring decelerations from 3.4 to 9.6 feet/sec/sec. were run at the high weight (runs 404 through 409) and at the low weight (runs 504 through 509) and only the heavy airplane, high deceleration case (run 404) taxed the system.

This is the same speed and distance combination as in run 004 (at 90000 lb.) and 504 (at 70000 lb.). The effect of the weight variation is seen in brake pressure comparisons, because the reverse thrust was set to the limit in all three cases. In cases requiring less deceleration (and hence, less reverse thrust), the thrust is not limited, and changes to reflect the airplane weight. The braking system is not significantly affected.

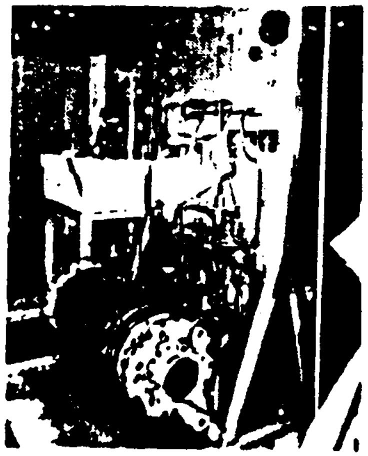
Headwinds and tailwinds of 25 feet/sec. (15 knots) were simulated for speed and distance combinations requiring decelerations between 3.9 and 7.8 feet/sec/sec. The speed error at the turn off in the tailwind cases (runs 601 to 603) was always less than 1 foot/sec., but the headwinds (in runs 701 to 703) caused low turn off speeds by 3 to 5 feet/sec. The reverse thrust computation did not take account of the additional drag due to wind and consequently, called for more reverse thrust than was necessary.



(a) MINICOMPUTERS
(AIRPLANE SIMULATION)



(b) ANALOG COMPUTERS
(TIRE,STRUT SIMULATION)



(c) BRAKE HYDRAULIC
HARDWARE

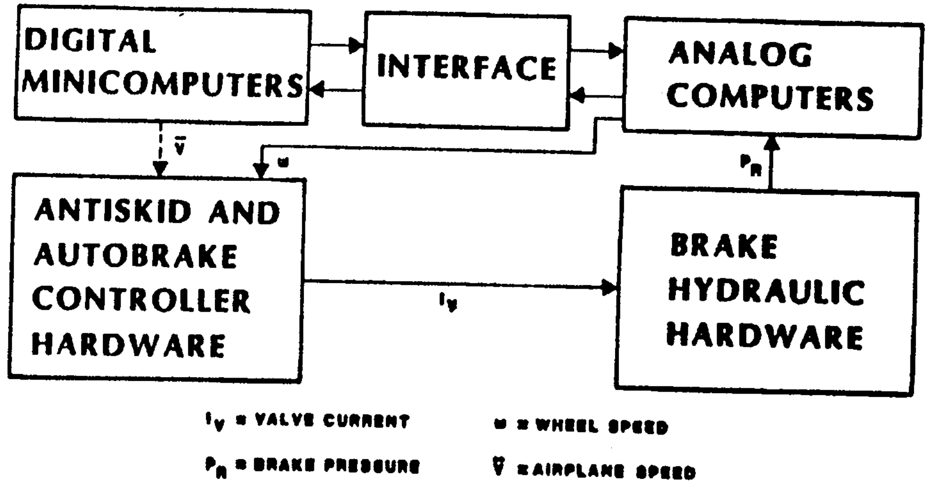


FIG 7 HYBRID BRAKE CONTROL LABORATORY

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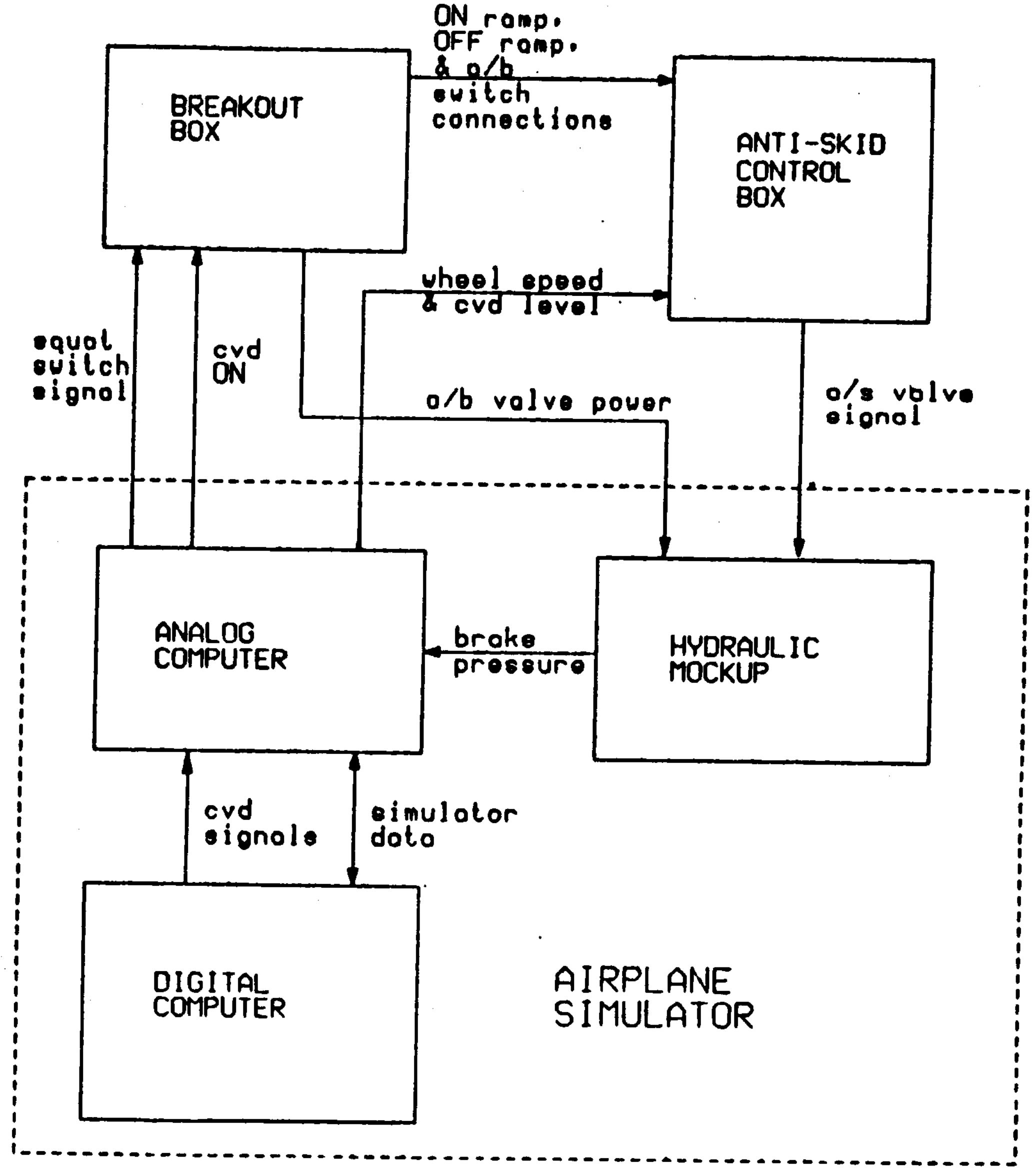

FIGURE 8: CV AUTOBRAKE TEST SETUP

TABLE 1: TEST CONDITIONS* AND SYSTEM EFFECTIVENESS

CODE NUMBER	TURN DISTANCE	INITIAL SPEED	DESIRED TURN SPEED	REQ'D AVG. DECEL	SPEED ERROR = ACTUAL TURN SPEED - DESIRED TURN SPEED							
					BASE LINE (000)	1/2 THRUST (100)	WET RNWY (200)	.2 MU (300)	110 KLB HEAVY WEIGHT (400)	70 KLB LIGHT WEIGHT (500)	TAIL WIND (600)	HEAD WIND (700)
01	1800.	202.	110.	7.8	-1.05	.12	.27				.01	-3.07
02	2300.	202.	110.	6.1	-.21	.25	.57				.82	-3.13
03	3600.	202.	110.	3.9	.58	.06	.41				.27	-4.38
04	1800.	202.	75.	9.6	.68	.45	24.53	.62	.47	.15		
05	2300.	202.	75.	7.5	-.46	.53	1.02		.98	.43		
06	3600.	202.	75.	4.8	1.30	.47	1.08		.65	.82		
07	1800.	202.	125.	6.8	-.94				-1.10	-.61		
08	2300.	202.	125.	5.3	-.27				-.73	.05		
09	3600.	202.	125.	3.4	.02				-.09	-.35		
10	1800.	228.	75.	13.1	42.32							
11	2300.	228.	75.	10.2	.74							
12	3600.	228.	75.	6.6	.86							
13	1800.	185.	125.	5.2	-.36							
14	2300.	185.	125.	4.0	.08							
15	3600.	185.	125.	2.6	-.55							

TABLE 2: WET RUNWAY FRICTION MODEL

AIRPLANE SPEED	0.	34.	52.	90.	130.	180.	195.
FRICTION COEFFICIENT	.5	.365	.3	.2	.125	.06	.06

ALL DISTANCES ARE IN FEET
ALL SPEEDS ARE IN FEET/SEC
ALL DECELERATIONS ARE IN FEET/SEC/SEC

*RUN NUMBERS ARE FORMED BY COMBINING THE THREE DIGIT NUMBER AT THE TOP OF THE COLUMN WITH THE CODE NUMBER IN THE FIRST COLUMN.

FIGURE 9: TEST MATRIX

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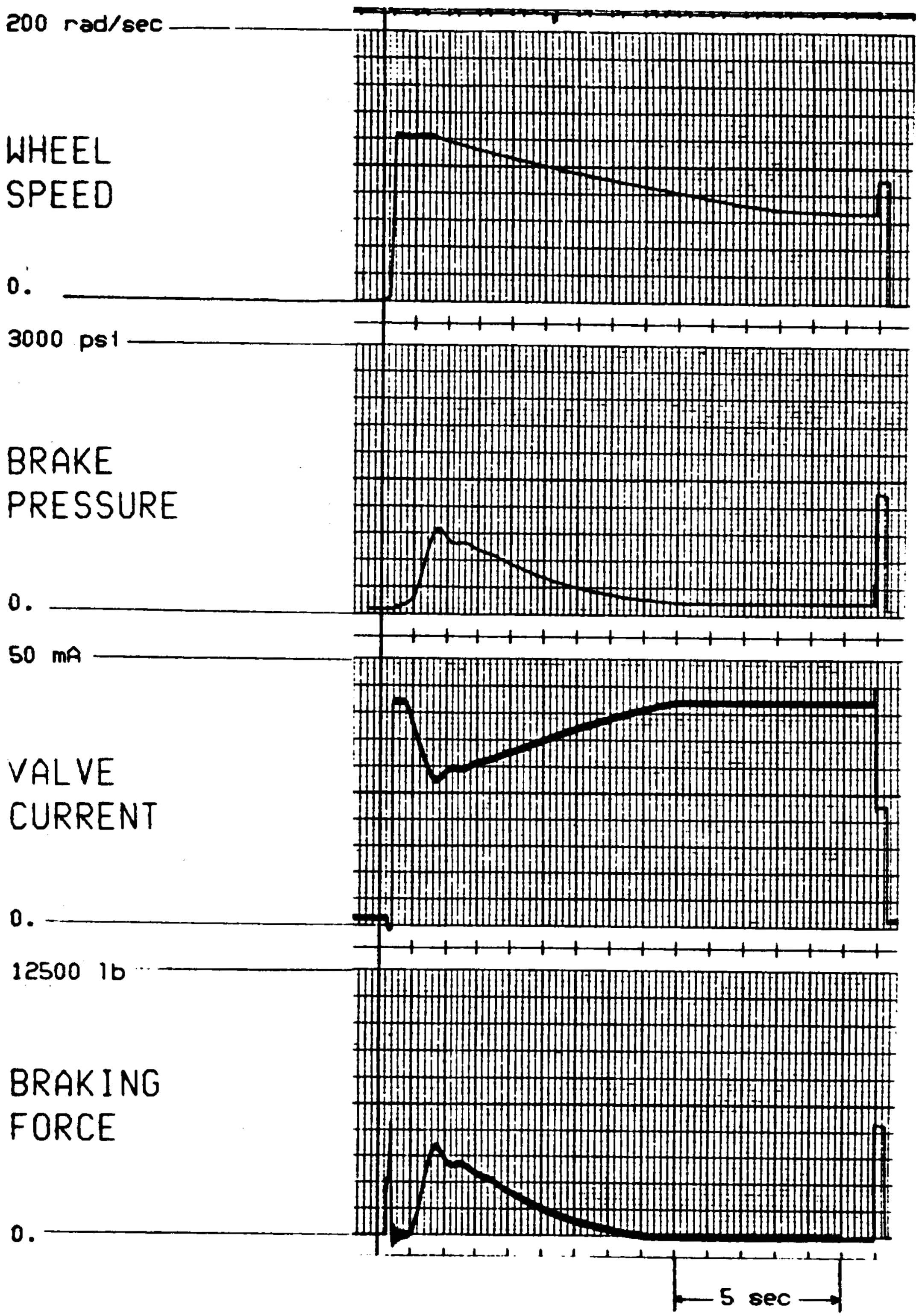

FIGURE 10 : TIME HISTORY DATA, RUN # 001

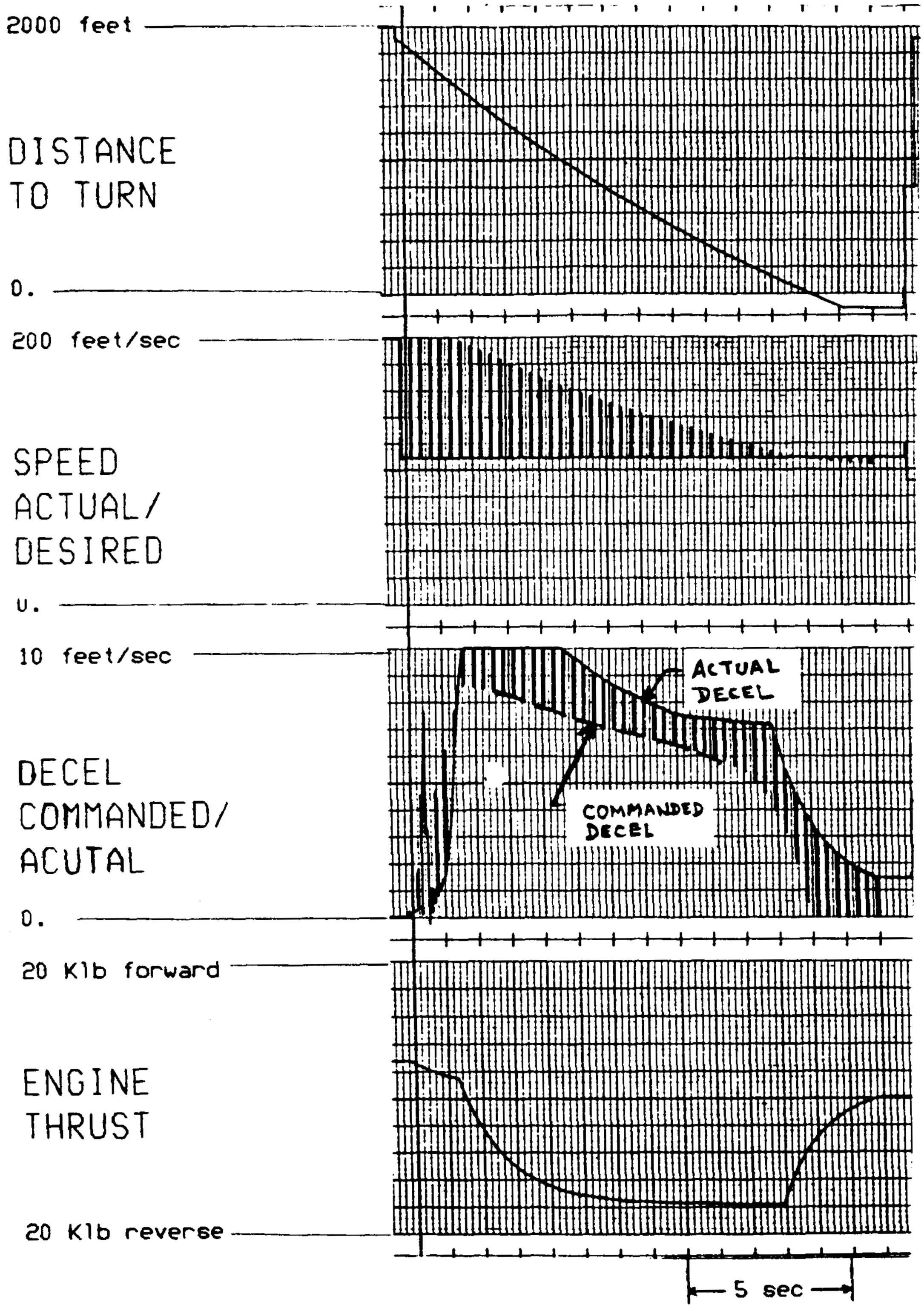

FIGURE 10 (cont'd): TIME HISTORY DATA, RUN # 001

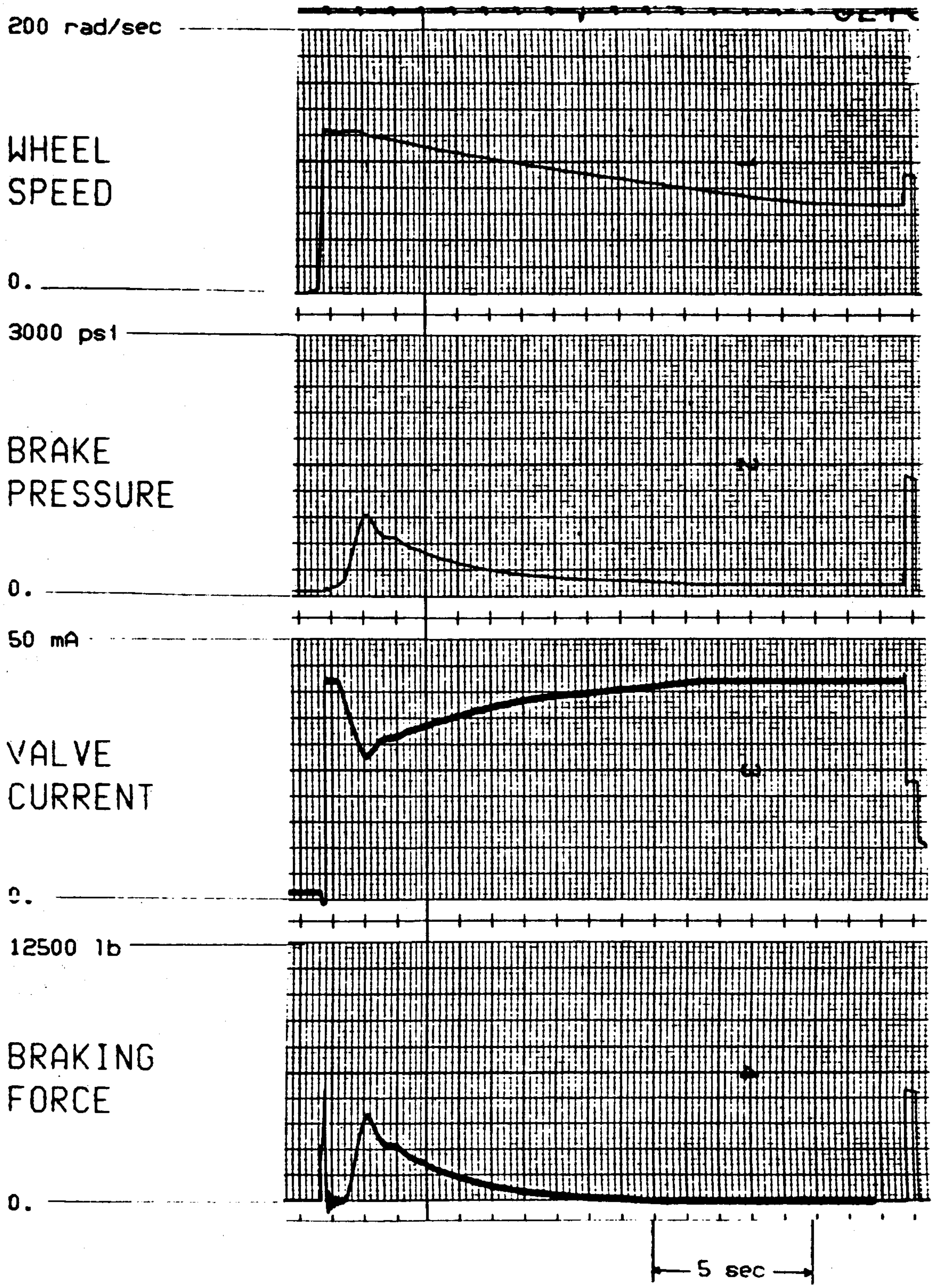

FIGURE 11 : TIME HISTORY DATA, RUN #002

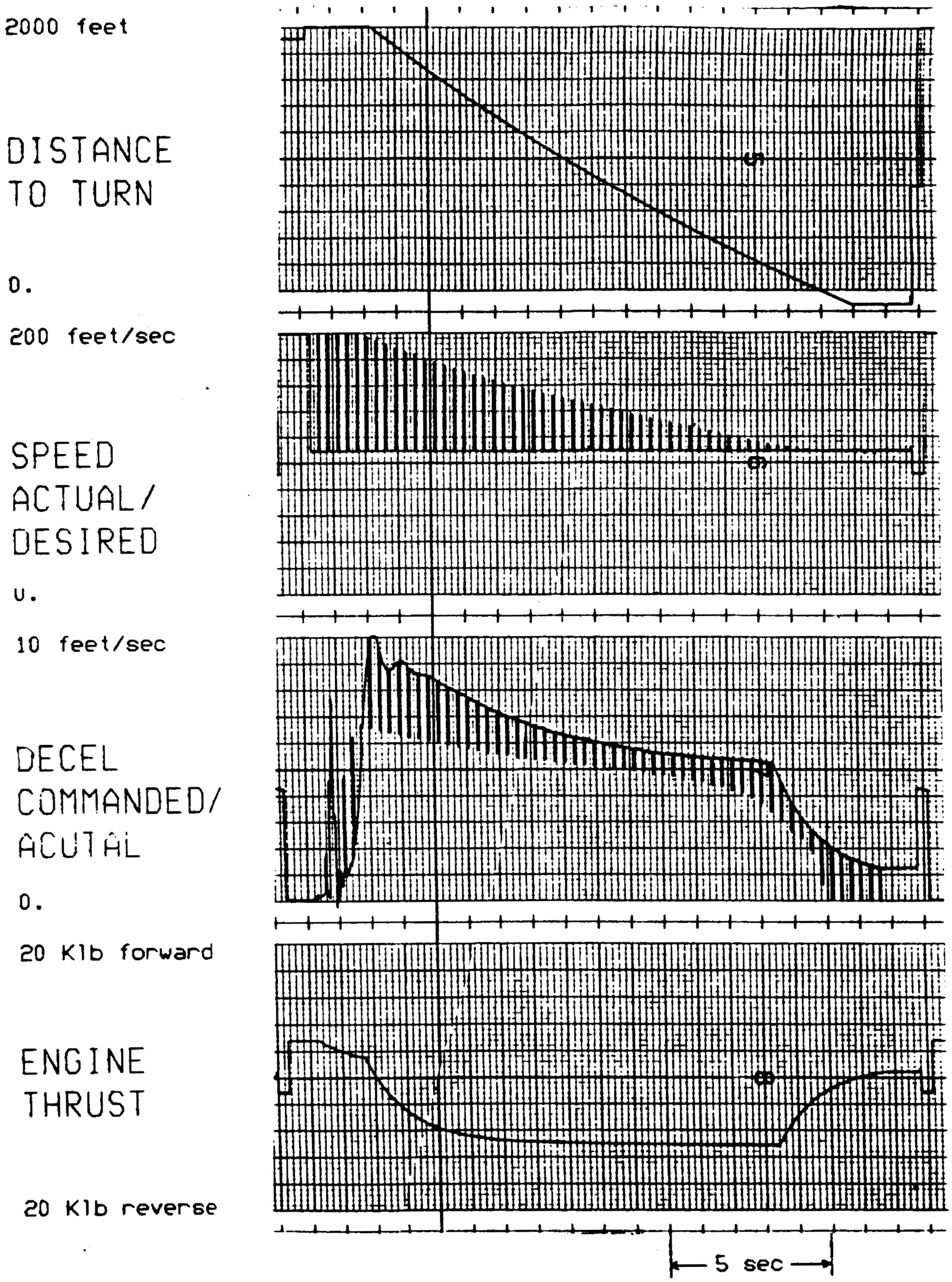

FIGURE 11 (cont'd): TIME HISTORY DATA, RUN # 002

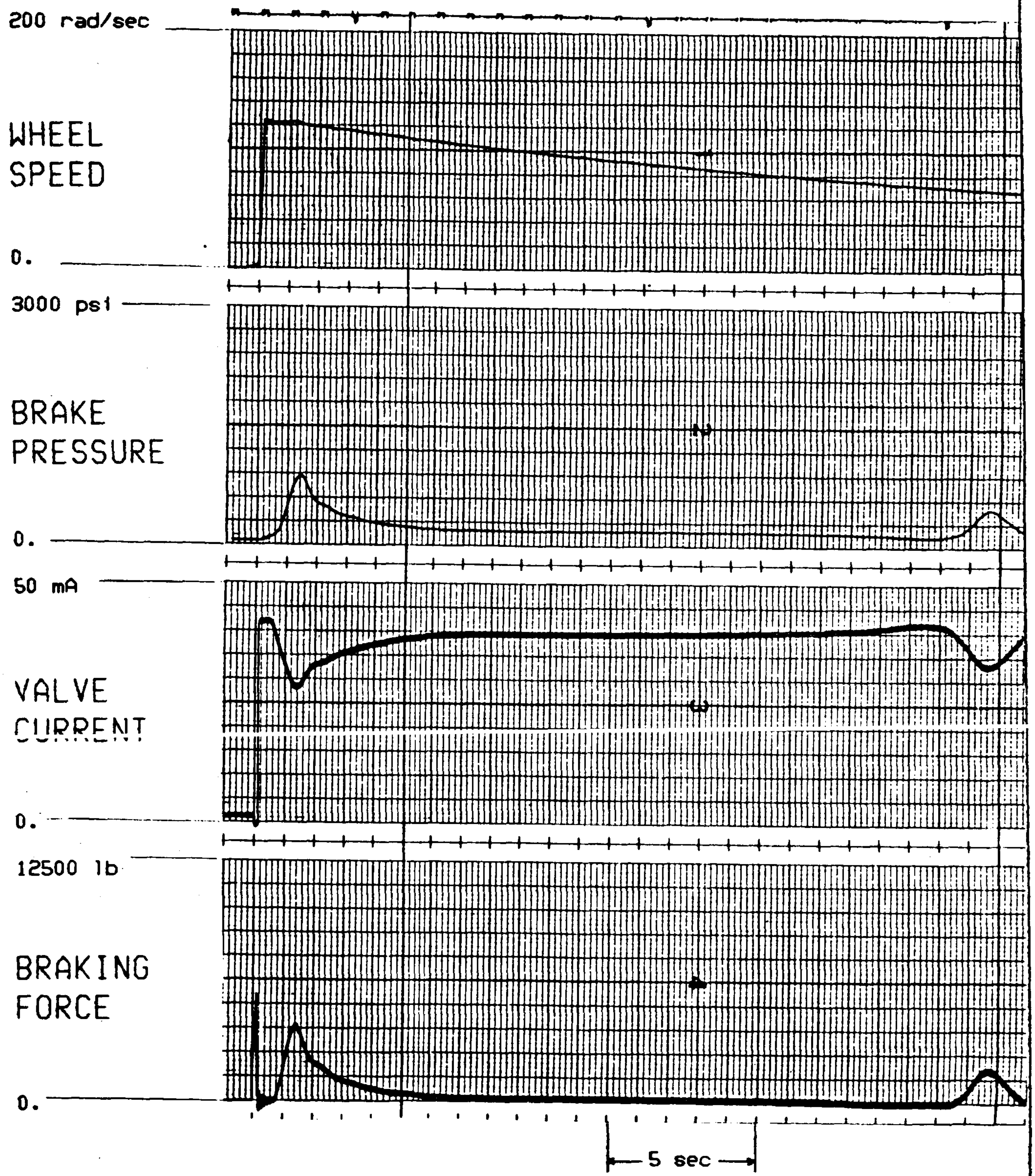

FIGURE 12 : TIME HISTORY DATA, RUN # 003

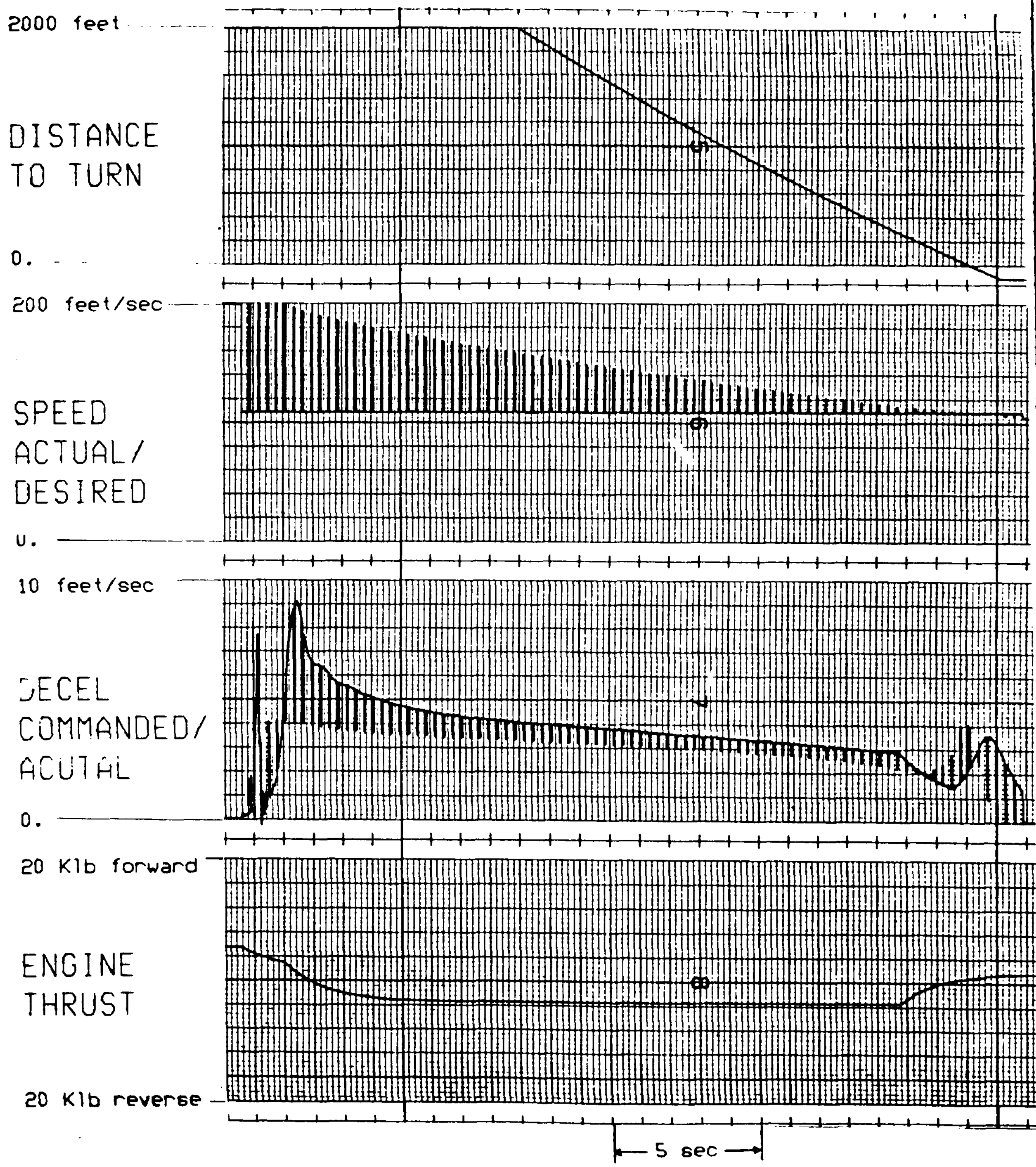

FIGURE 12 (cont'd): TIME HISTORY DATA, RUN #003

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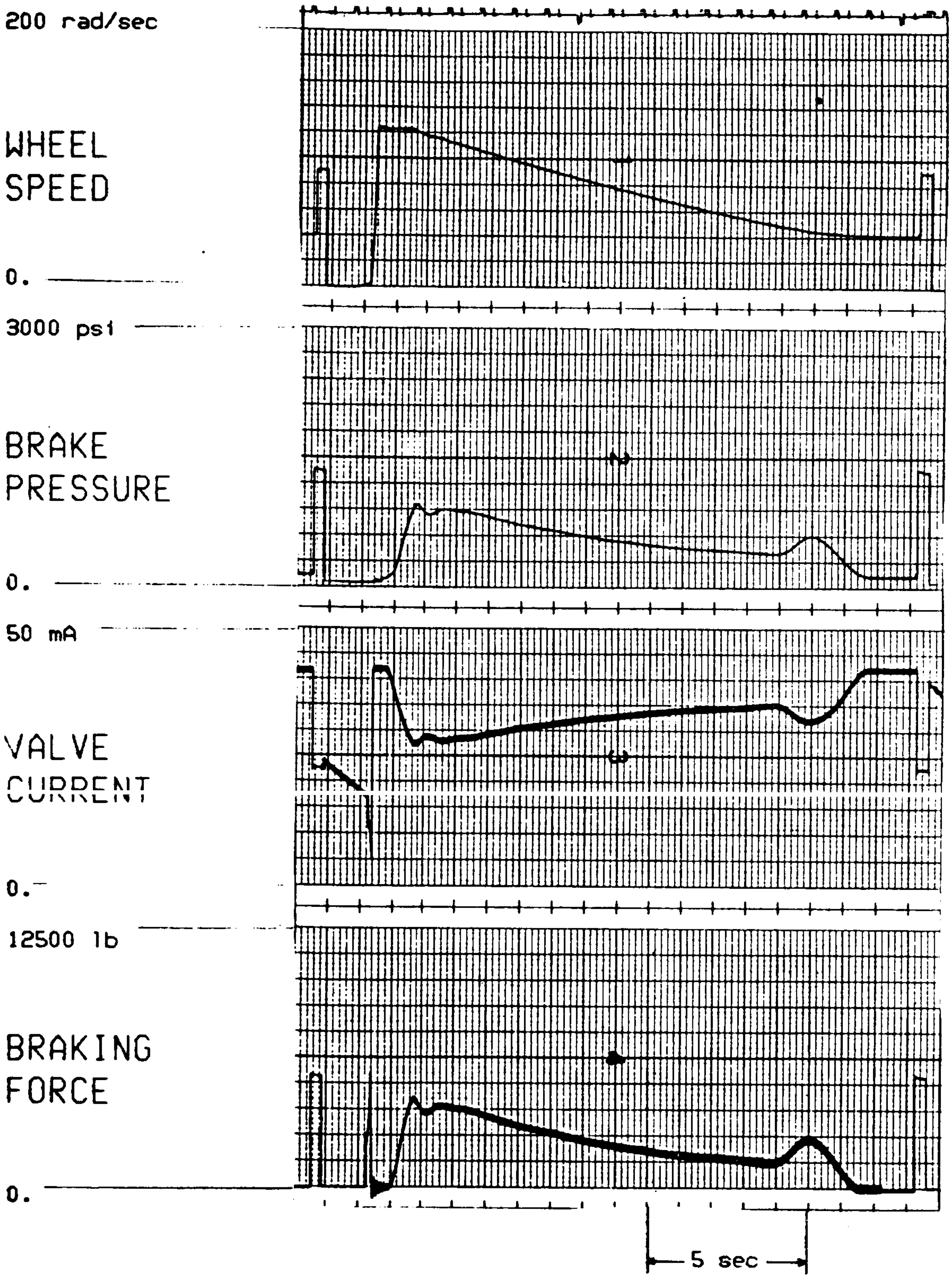

FIGURE 13 : TIME HISTORY DATA, RUN #004

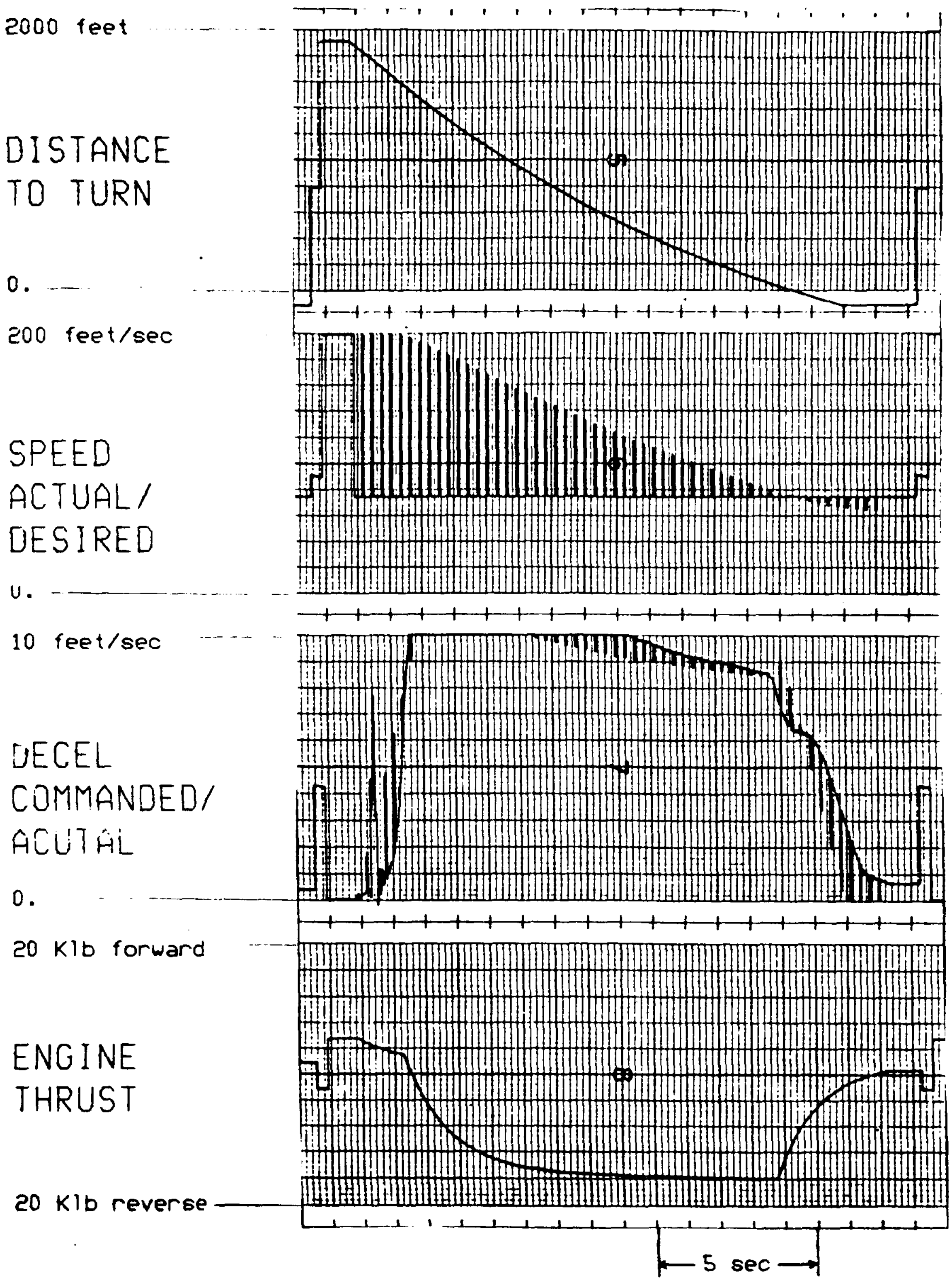

FIGURE 13 (cont'd): TIME HISTORY DATA, RUN #004

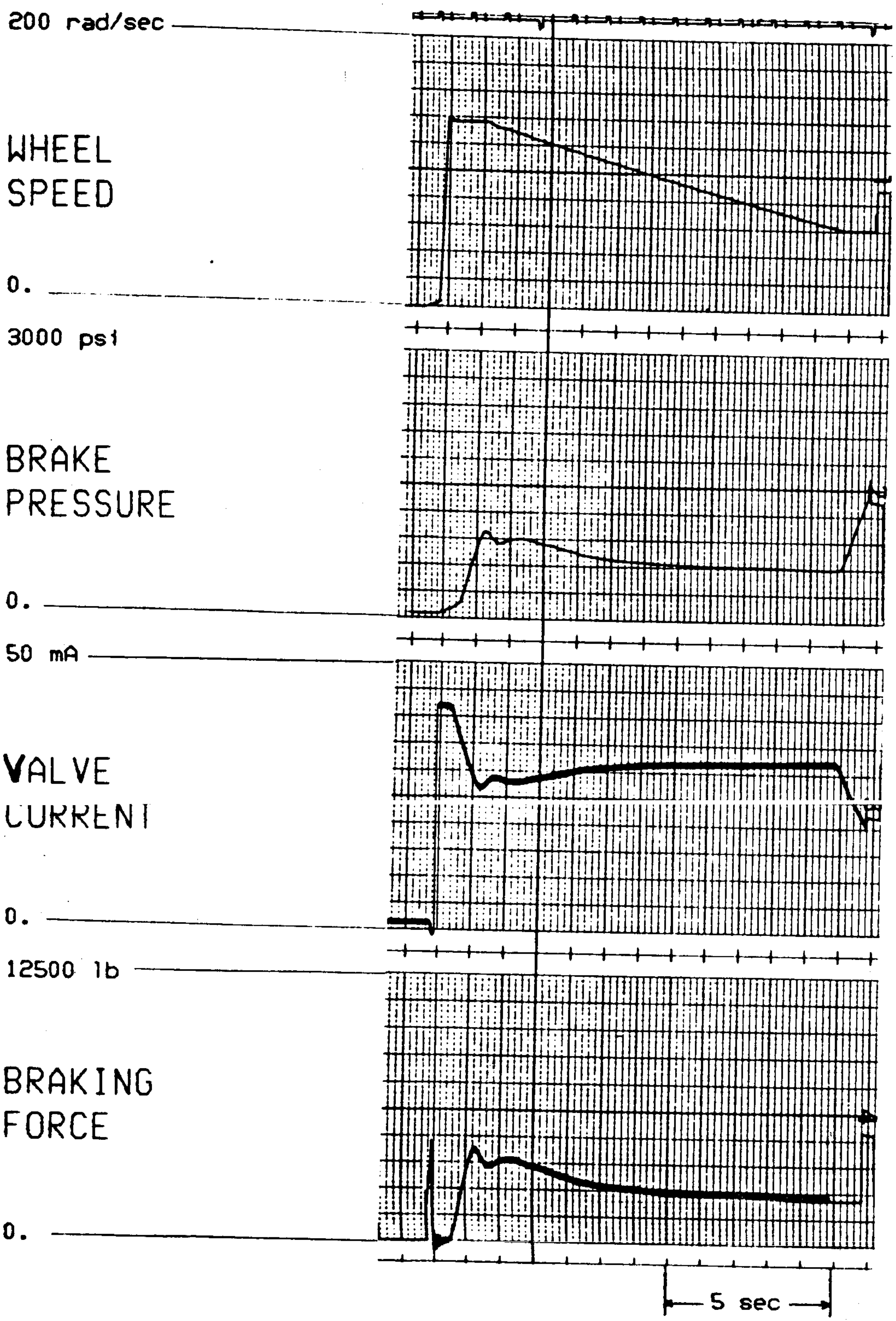

FIGURE 14 : TIME HISTORY DATA, RUN #010

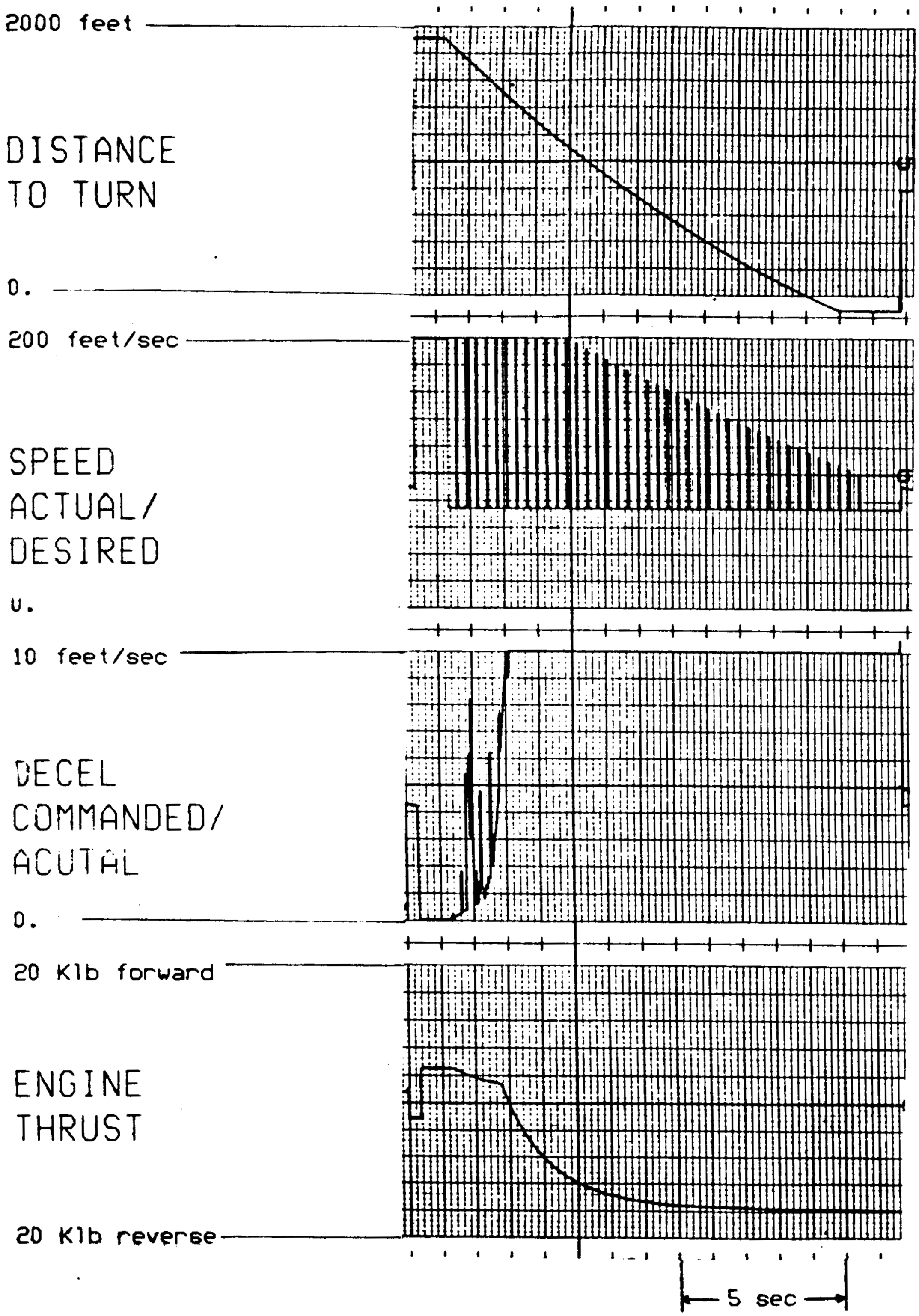

FIGURE 14 (cont'd): TIME HISTORY DATA, RUN # 010

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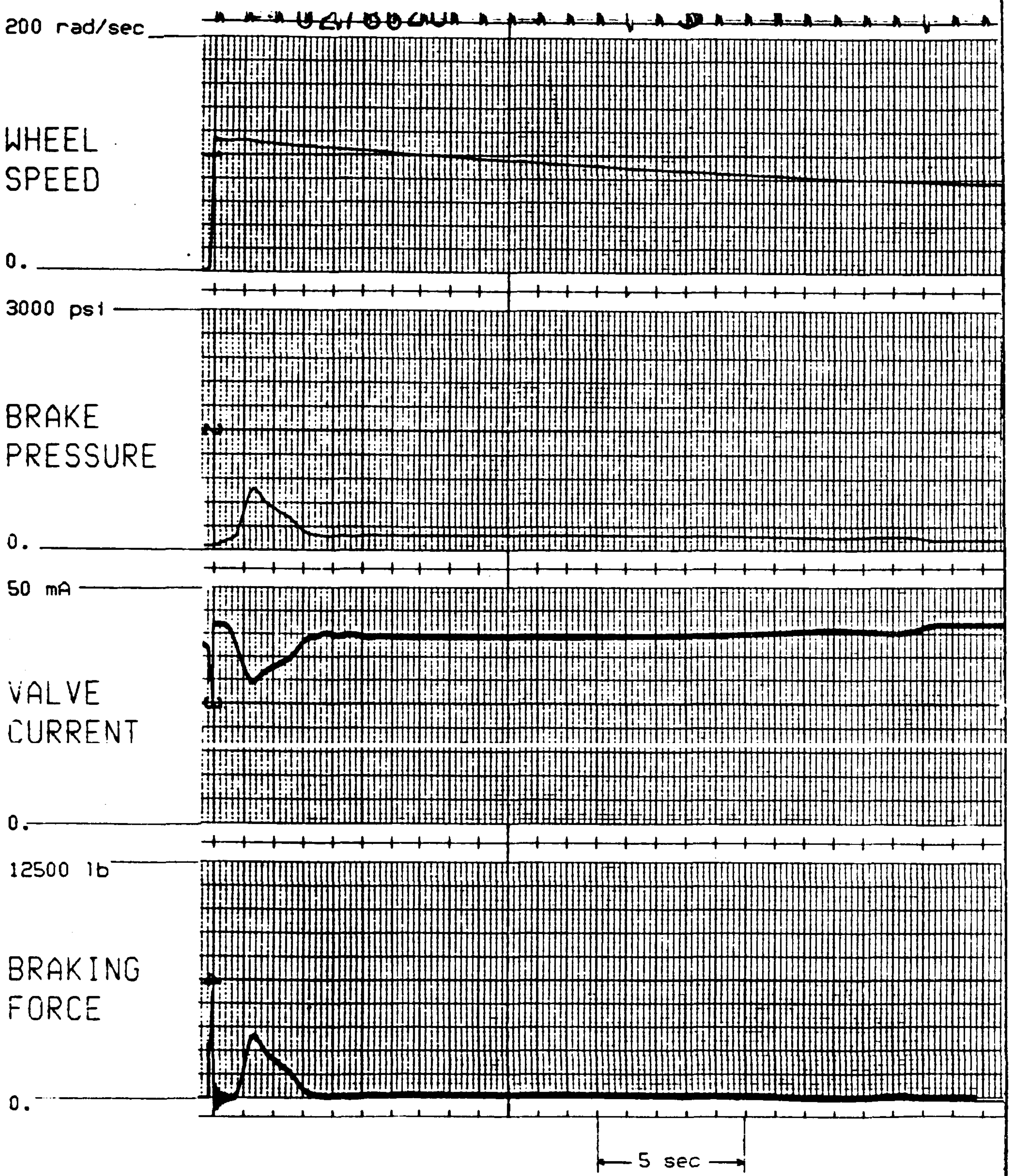

FIGURE 15 : TIME HISTORY DATA, RUN # 015

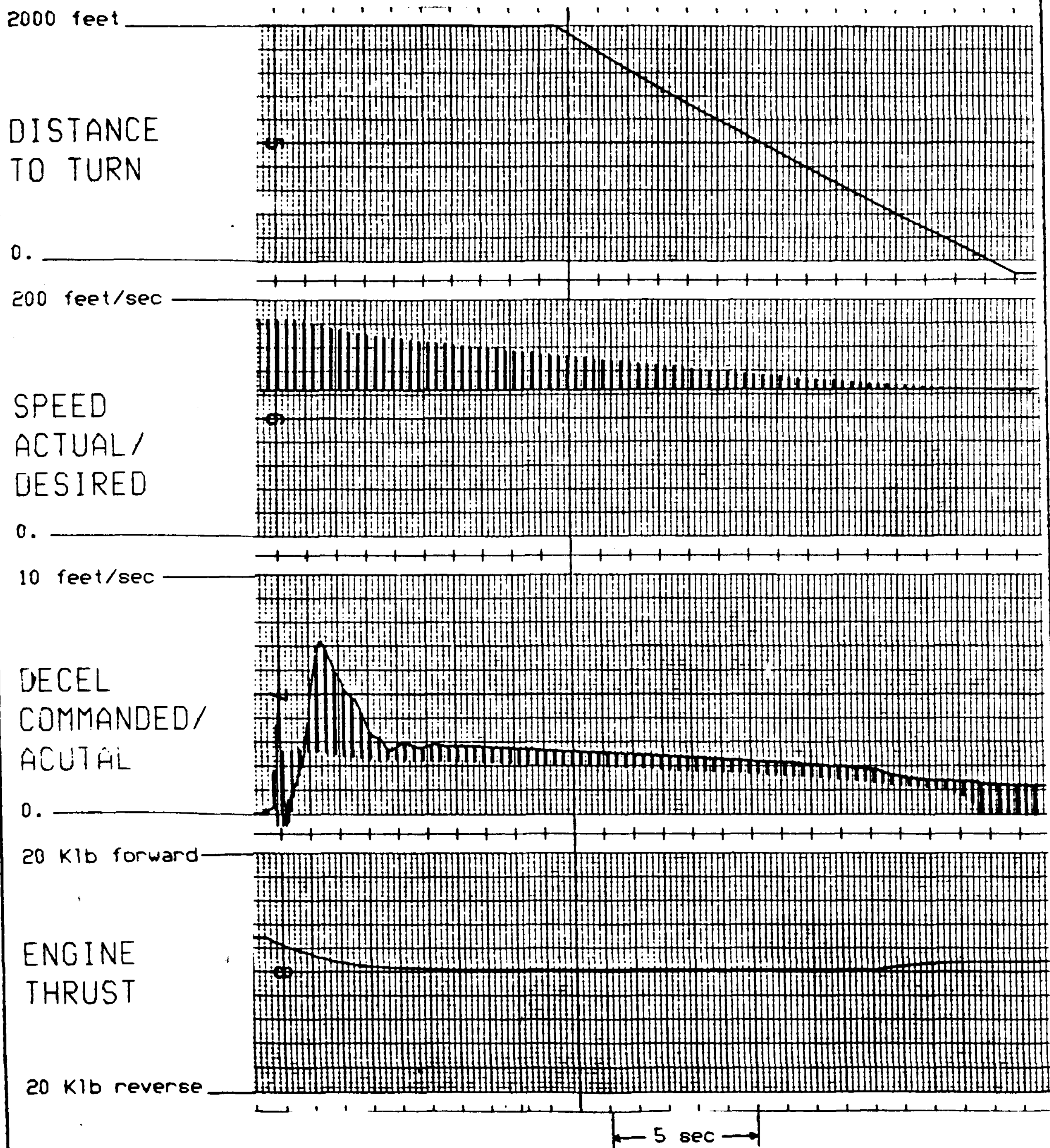

FIGURE 15 (cont'd): TIME HISTORY DATA, RUN #015

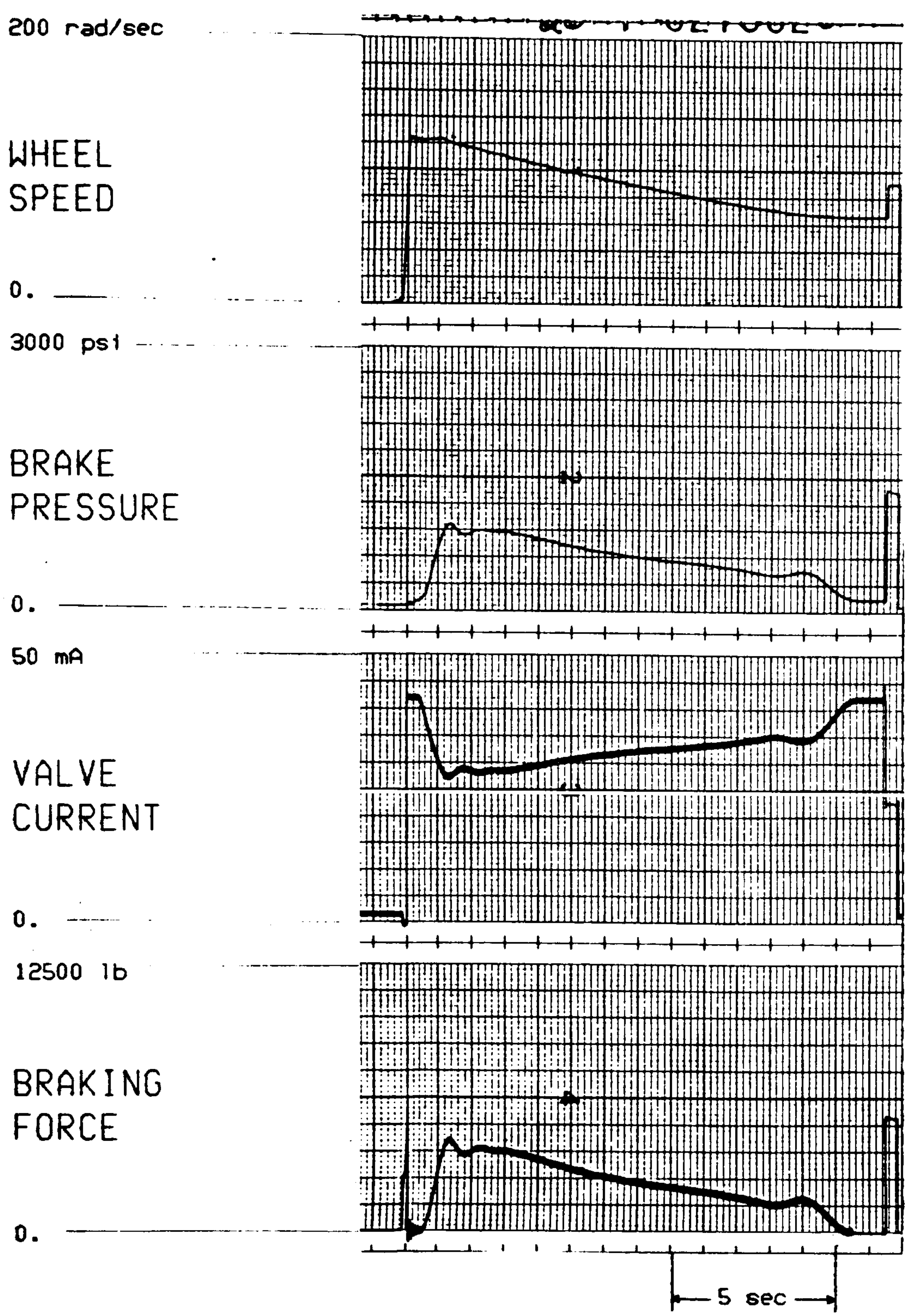

FIGURE 16 : TIME HISTORY DATA, RUN #101

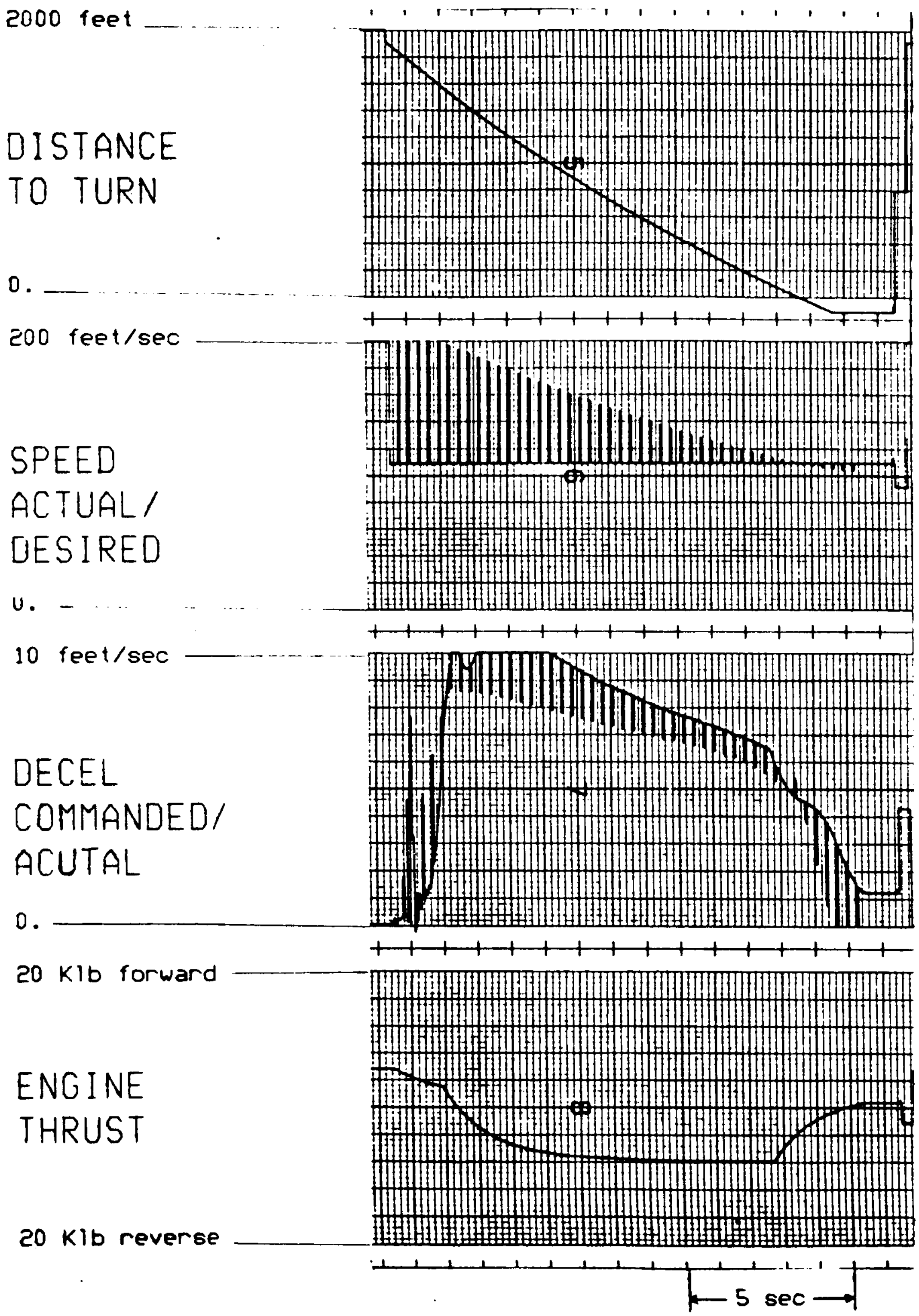

FIGURE 16 (cont'd): TIME HISTORY DATA, RUN #101

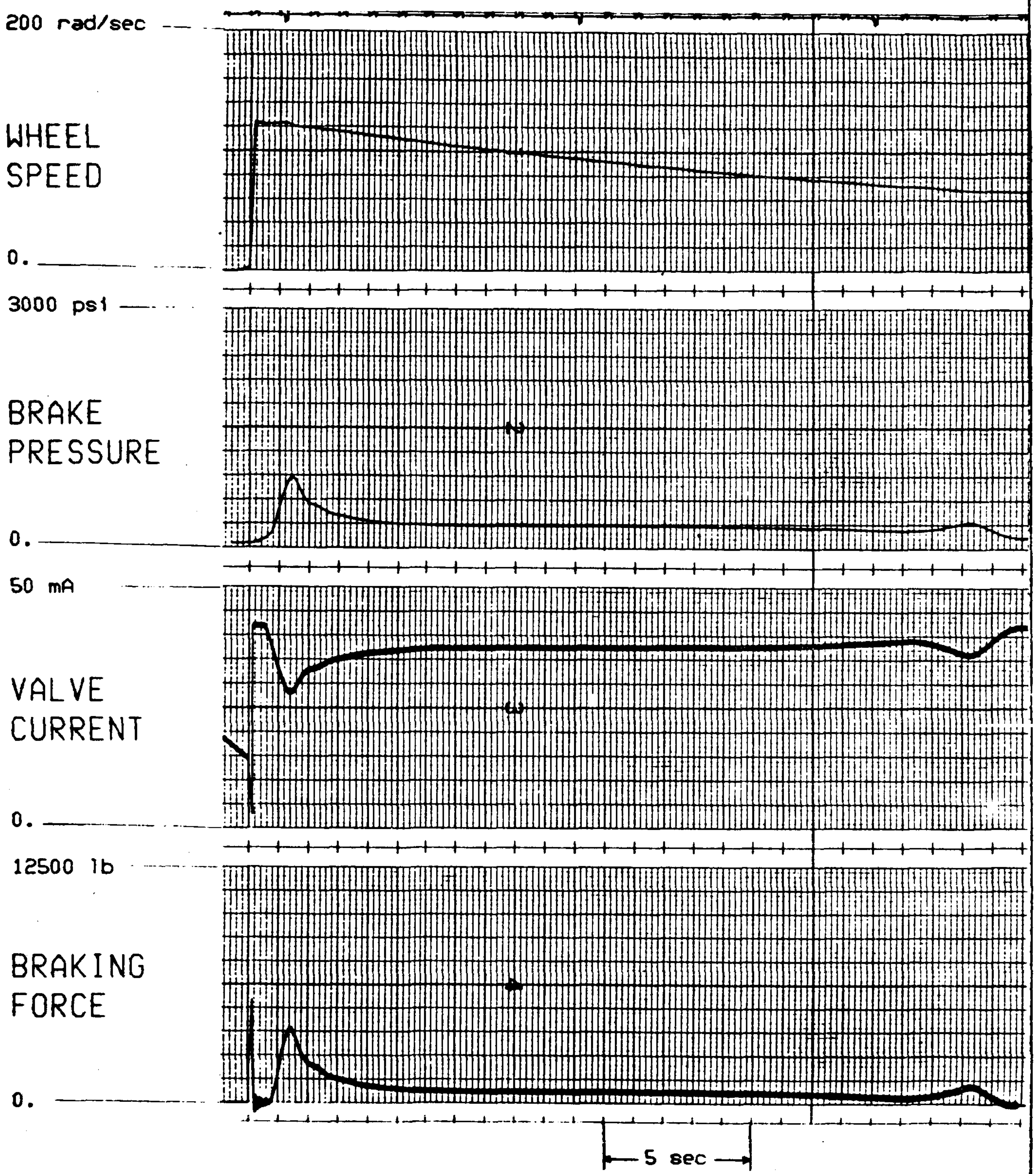

FIGURE 17 : TIME HISTORY DATA, RUN #103

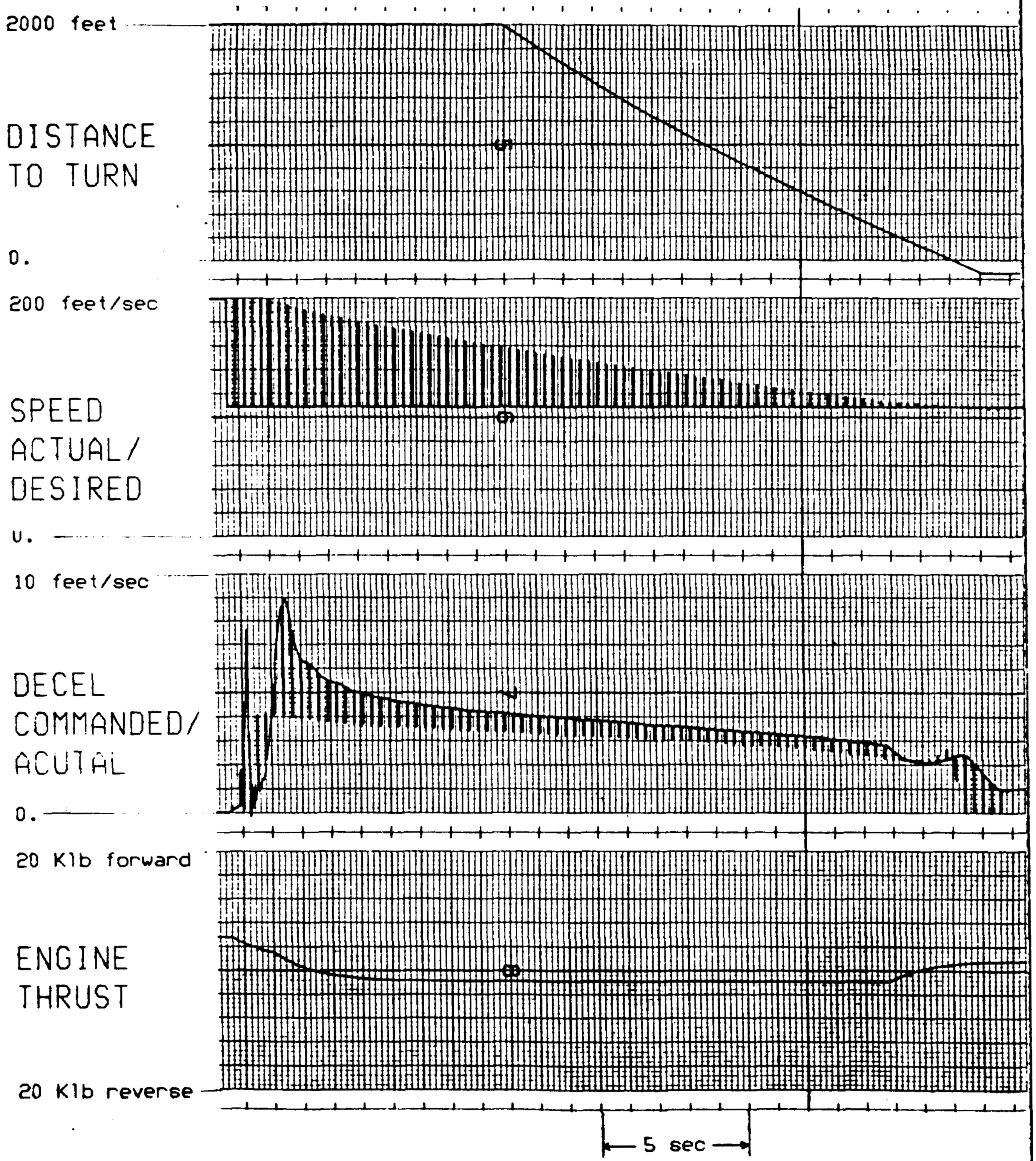

FIGURE 17 (cont'd): TIME HISTORY DATA, RUN #103

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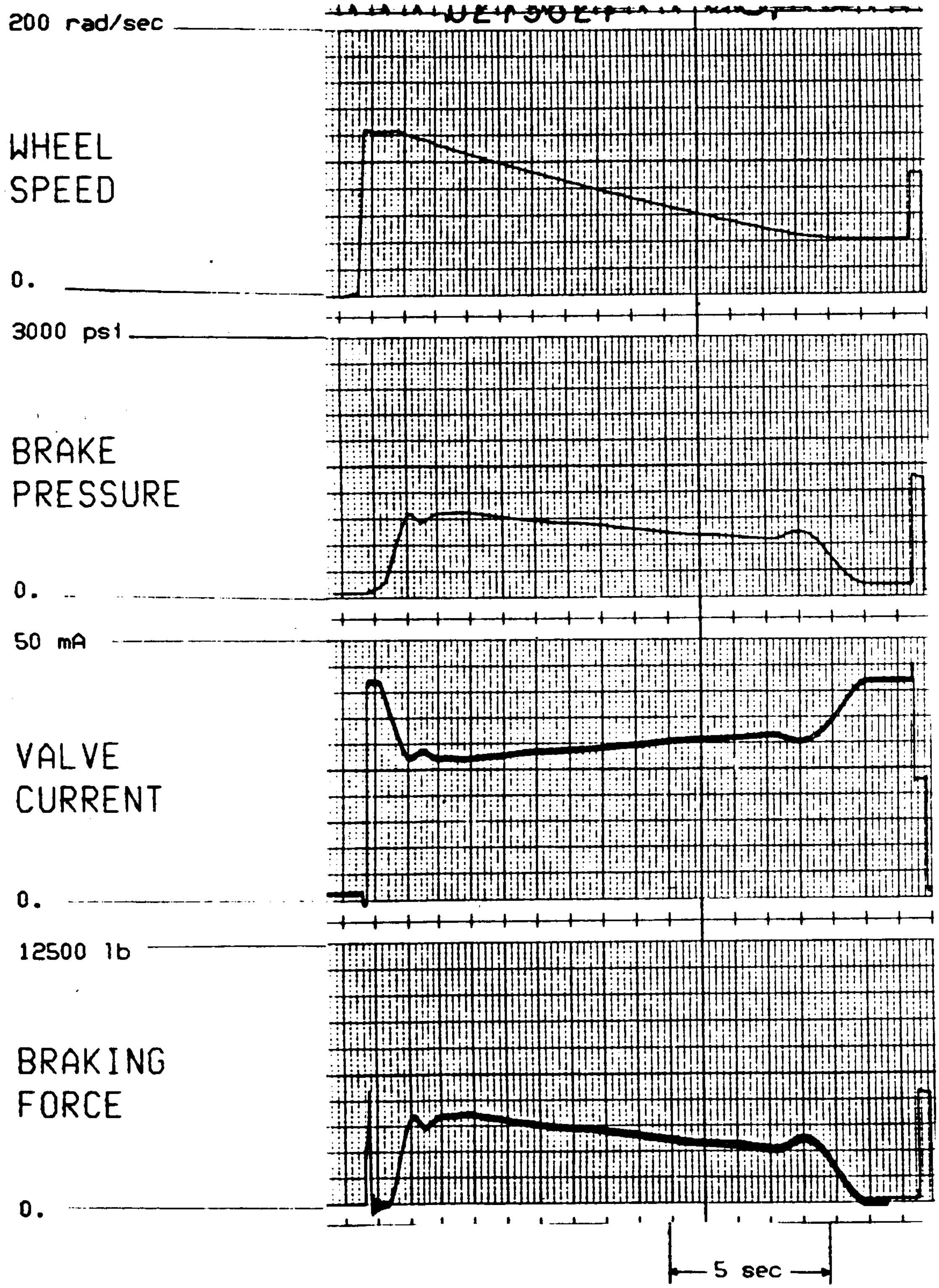

FIGURE 18 : TIME HISTORY DATA, RUN # 104

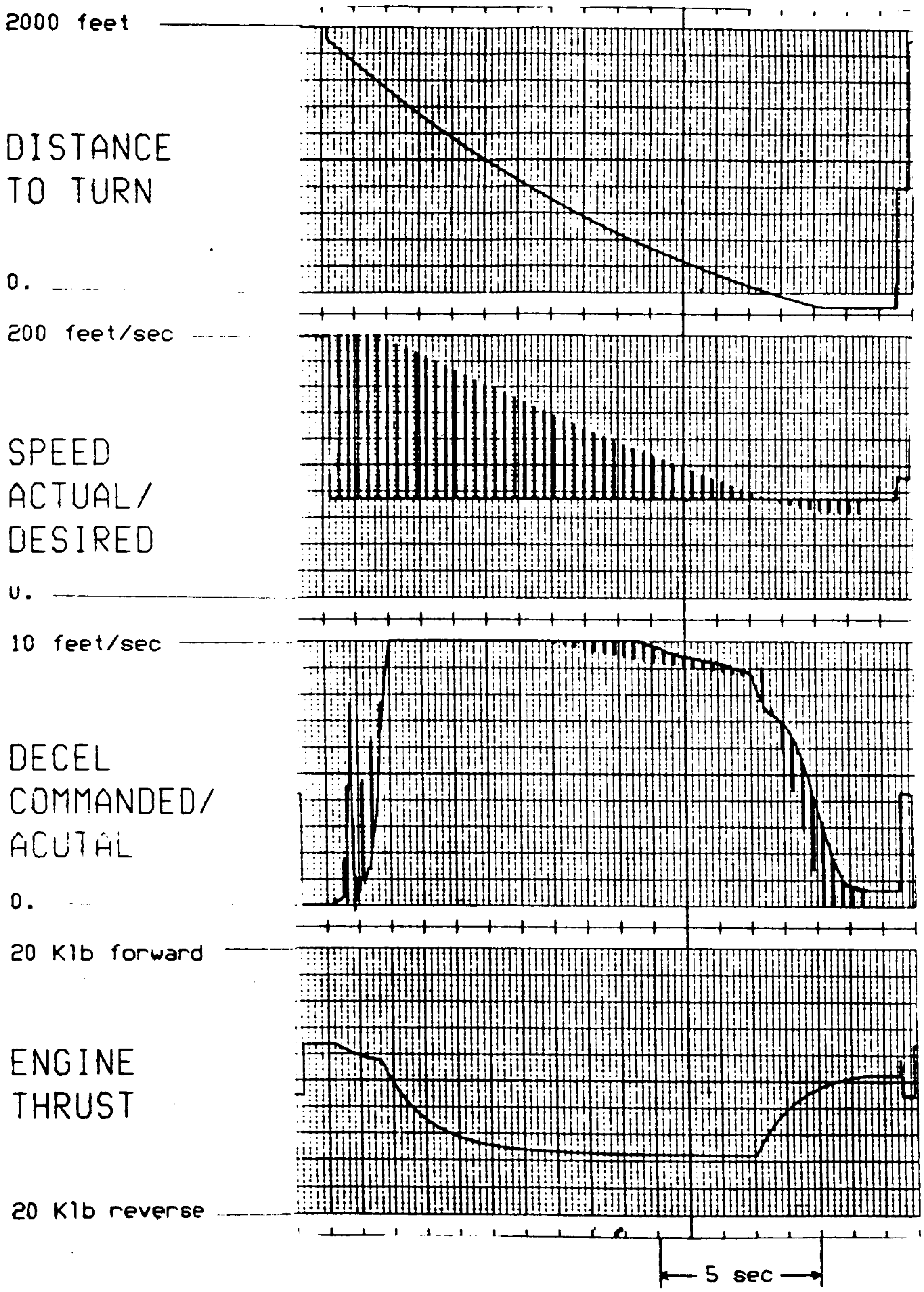

FIGURE 18 (cont'd): TIME HISTORY DATA, RUN #104

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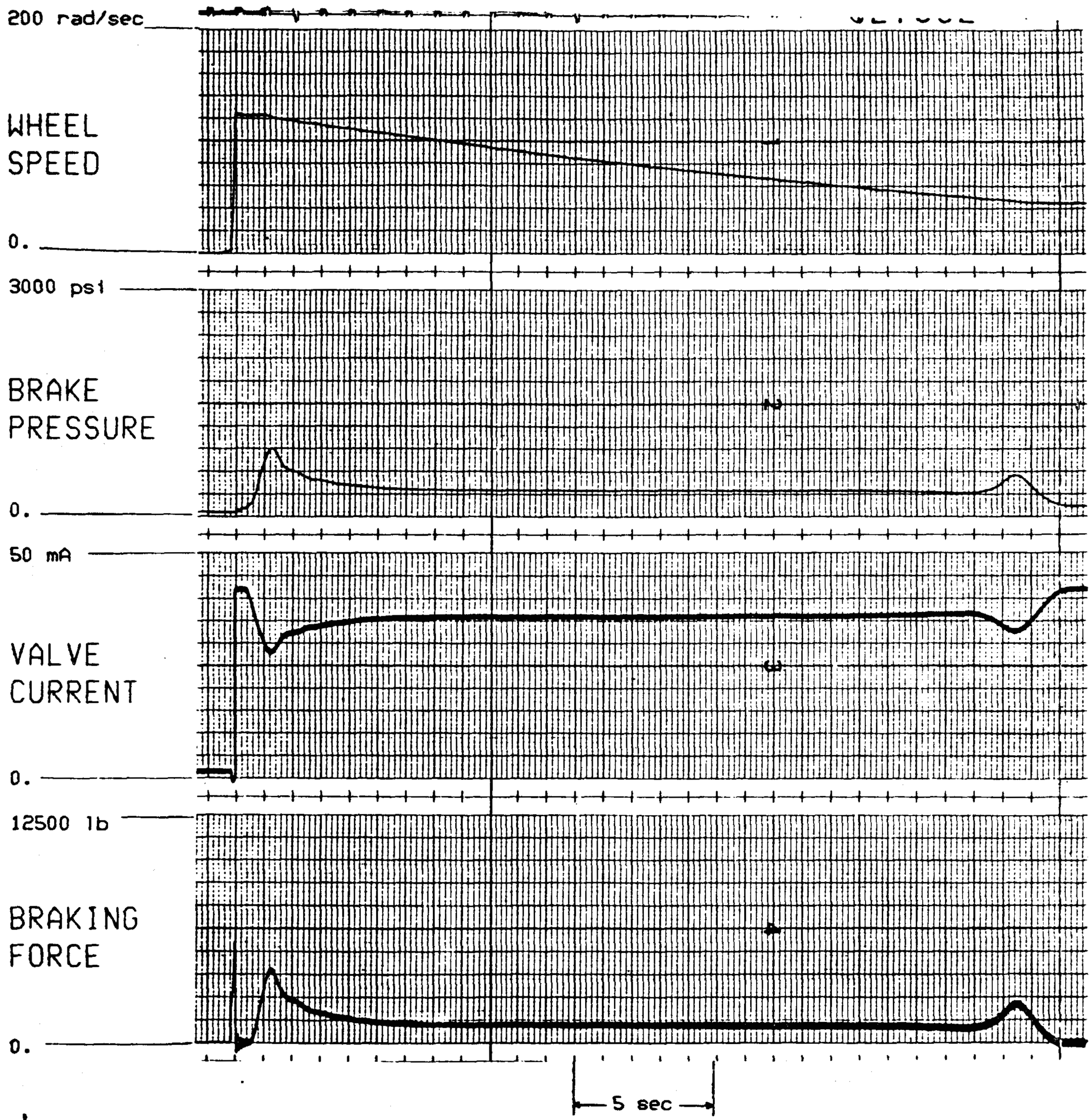

FIGURE 19 : TIME HISTORY DATA, RUN #106

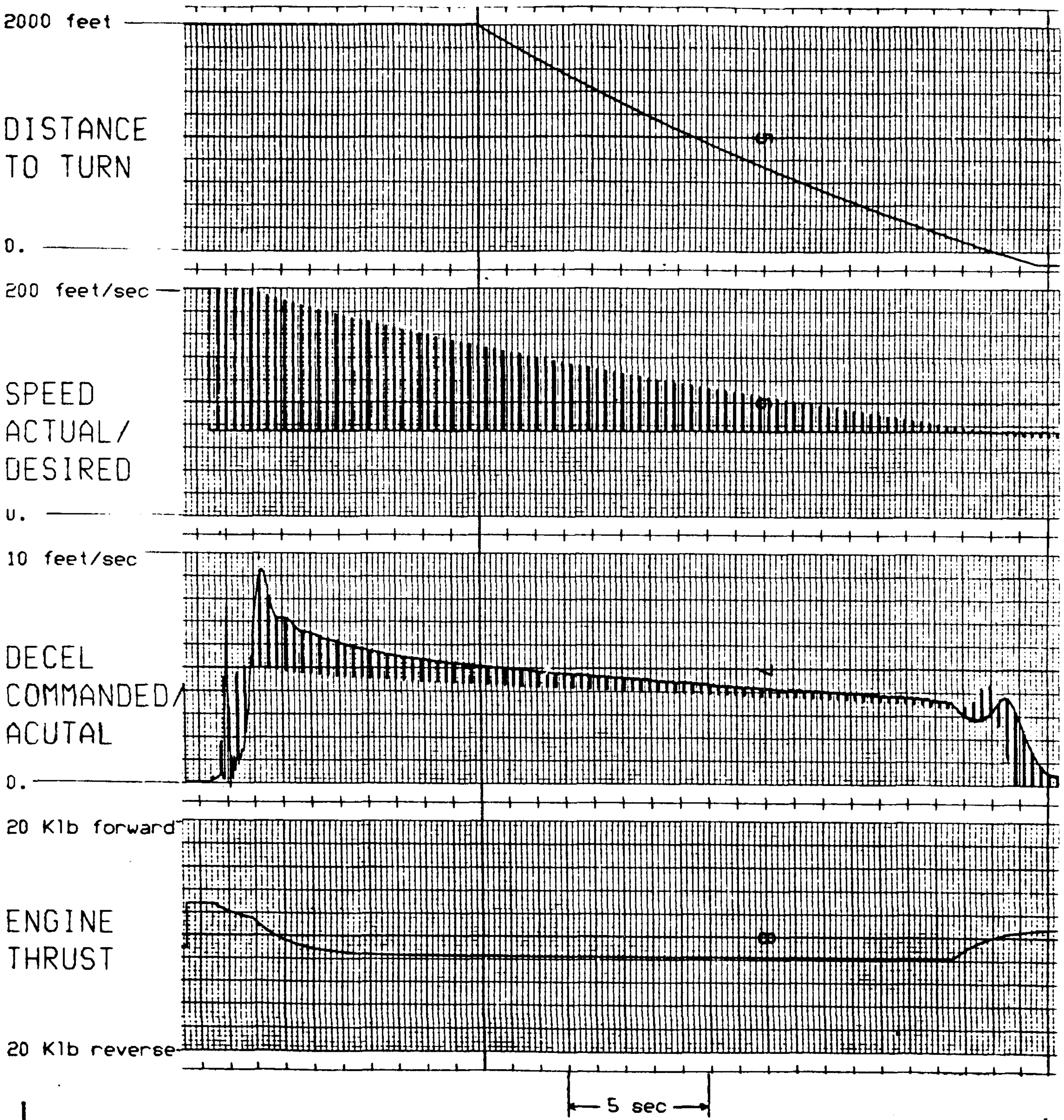

FIGURE 19 (cont'd): TIME HISTORY DATA, RUN #106

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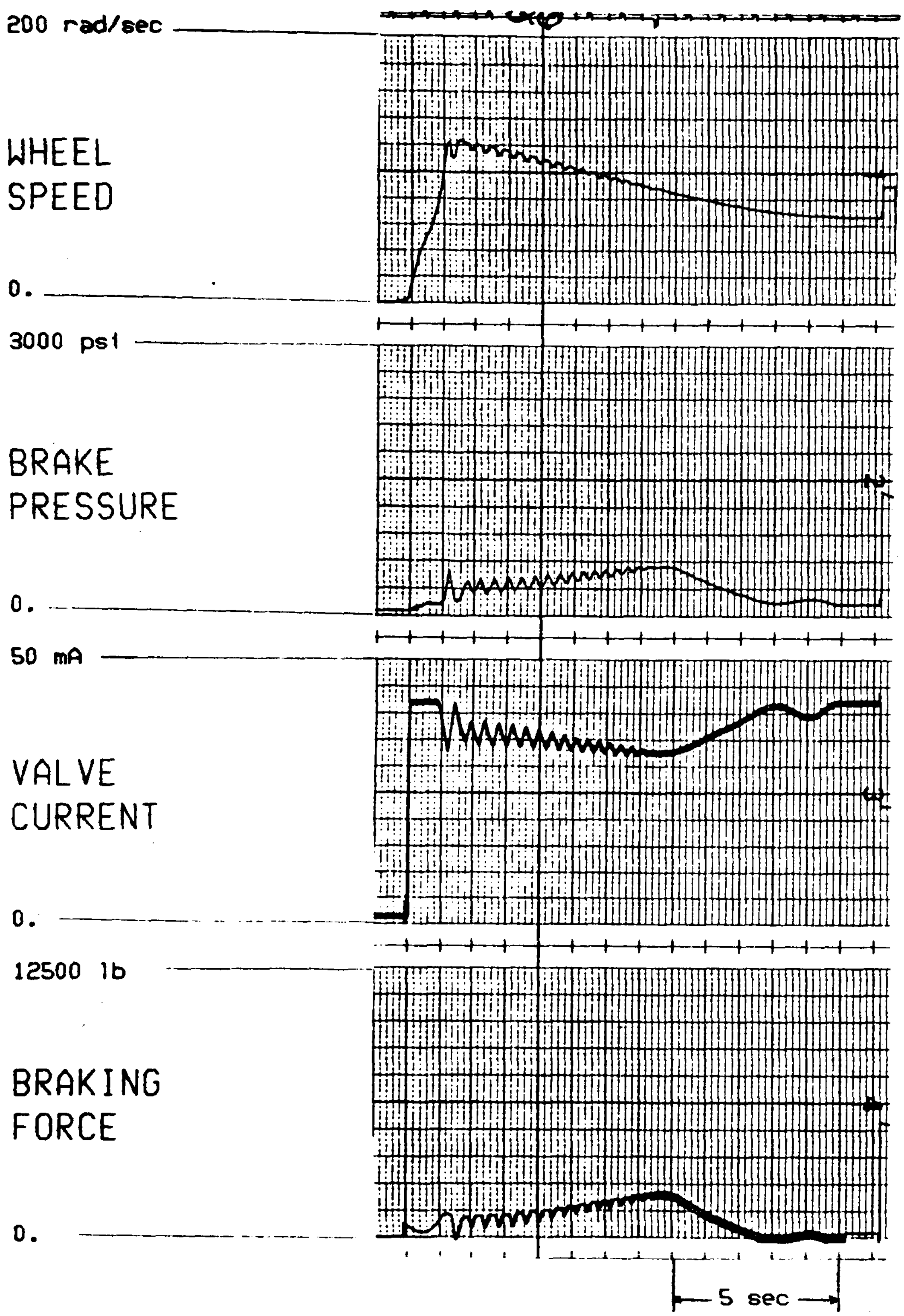

FIGURE 20: TIME HISTORY DATA, RUN #201

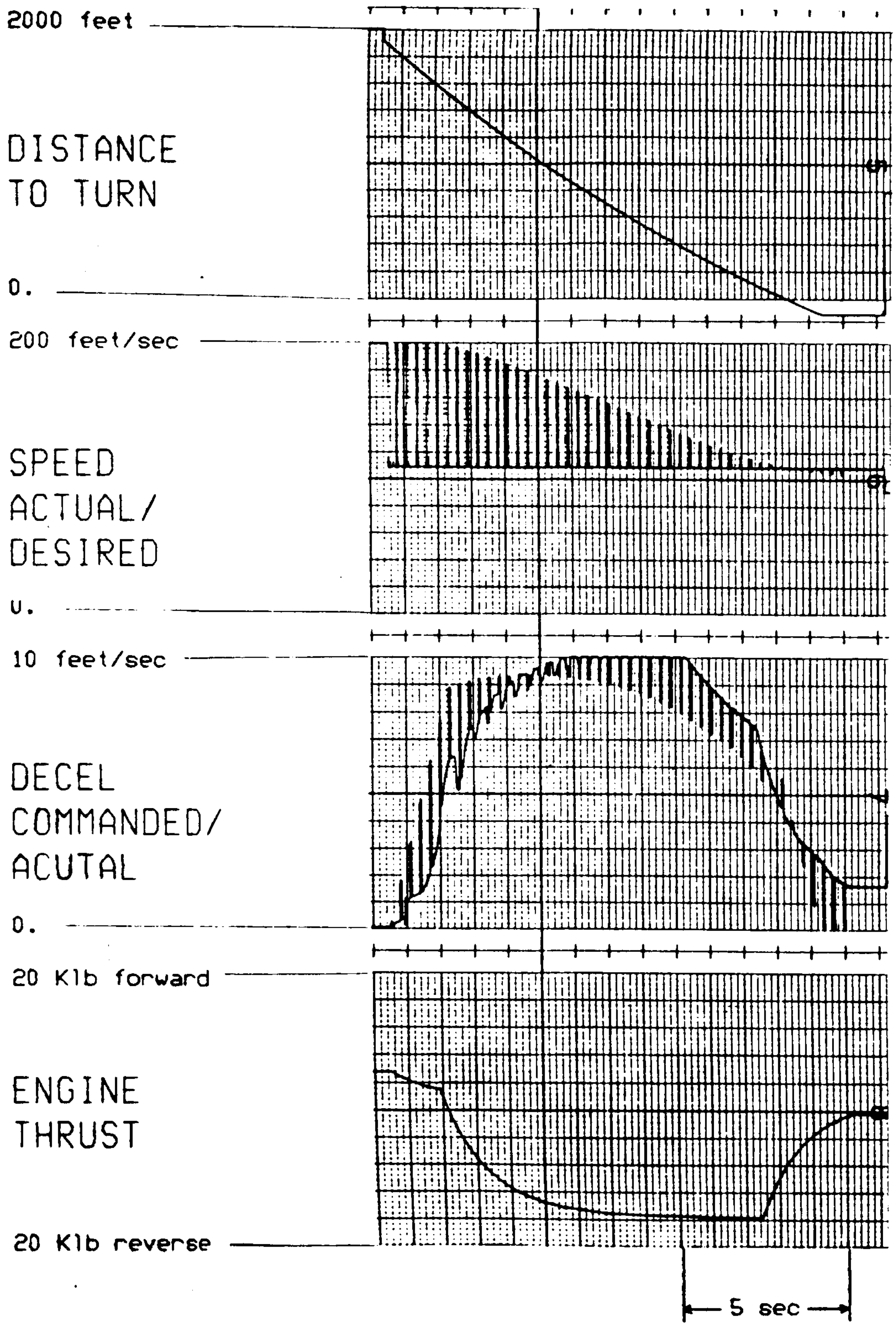

FIGURE 20 (cont'd): TIME HISTORY DATA, RUN # 201

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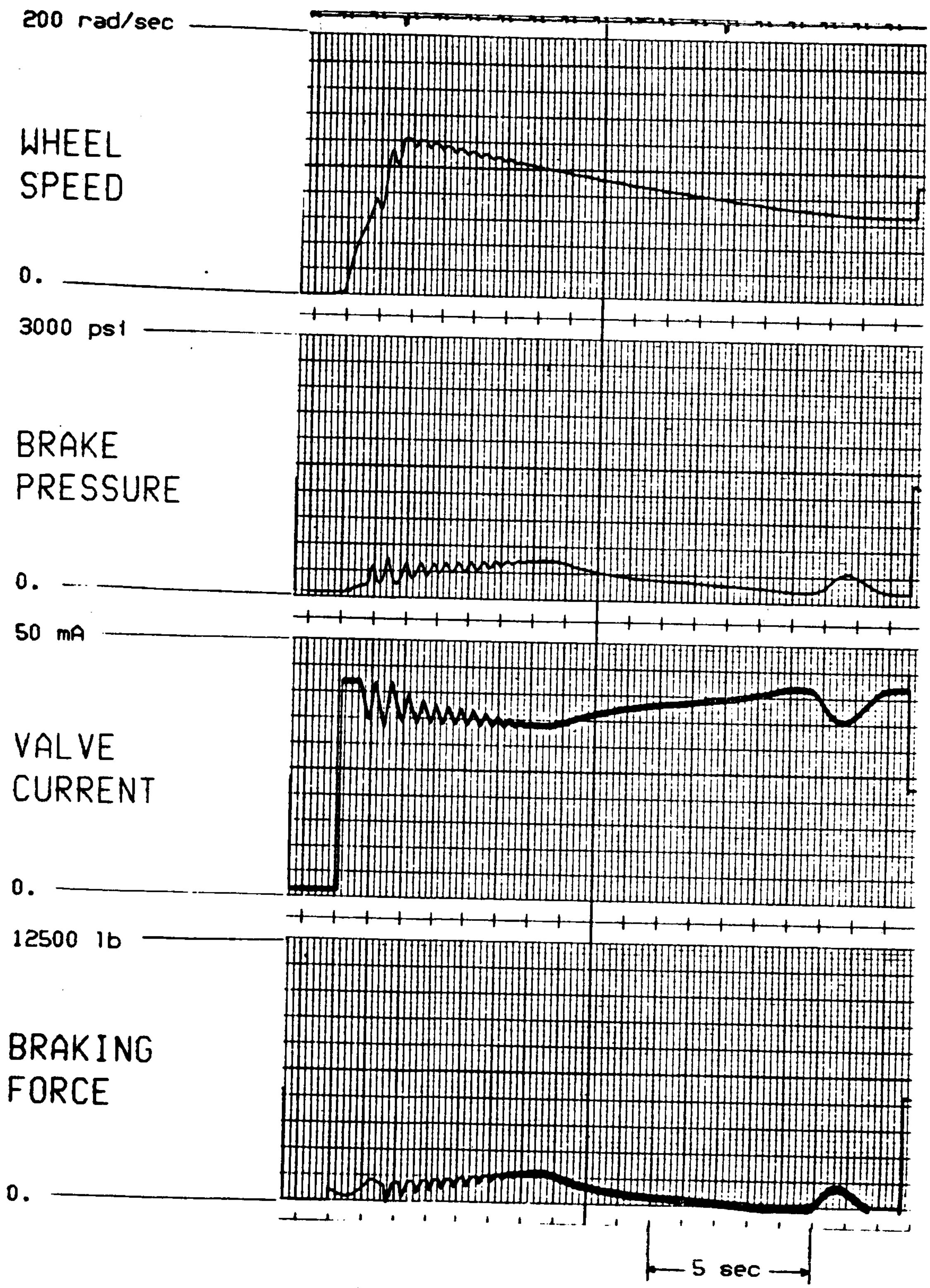

FIGURE 21 : TIME HISTORY DATA, RUN # 202

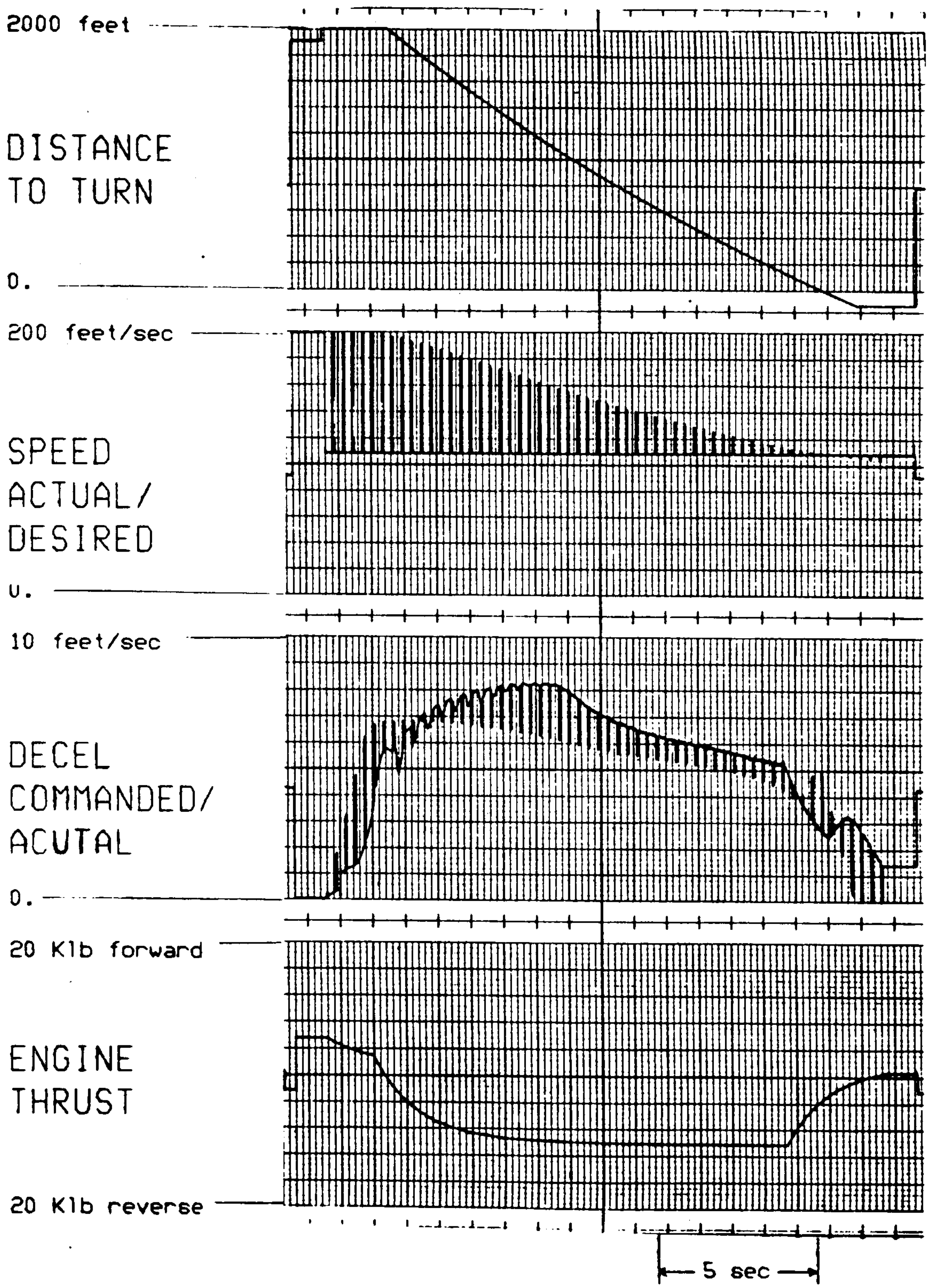

FIGURE 21 (cont'd): TIME HISTORY DATA, RUN #202

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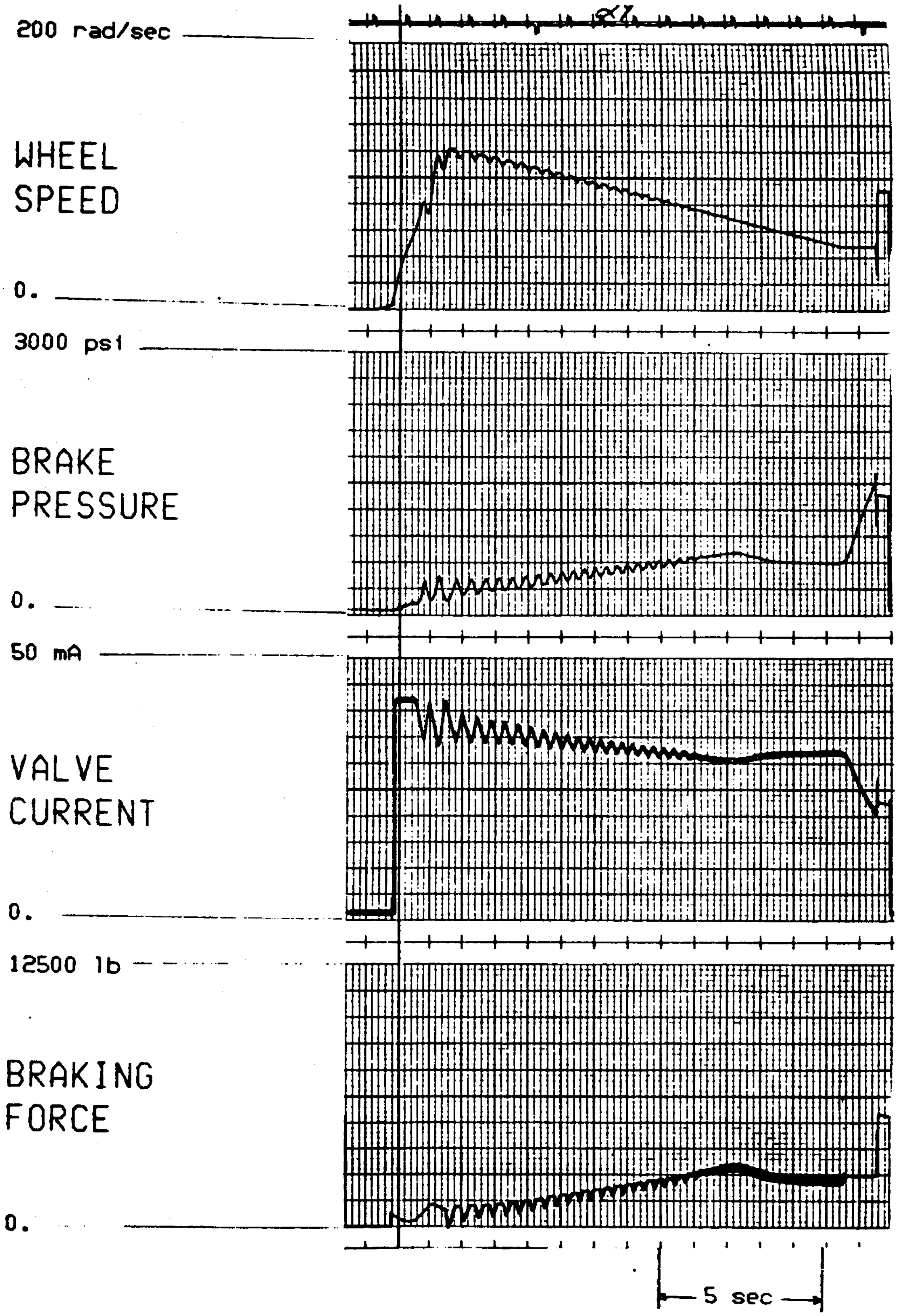

FIGURE 22 : TIME HISTORY DATA, RUN # 204

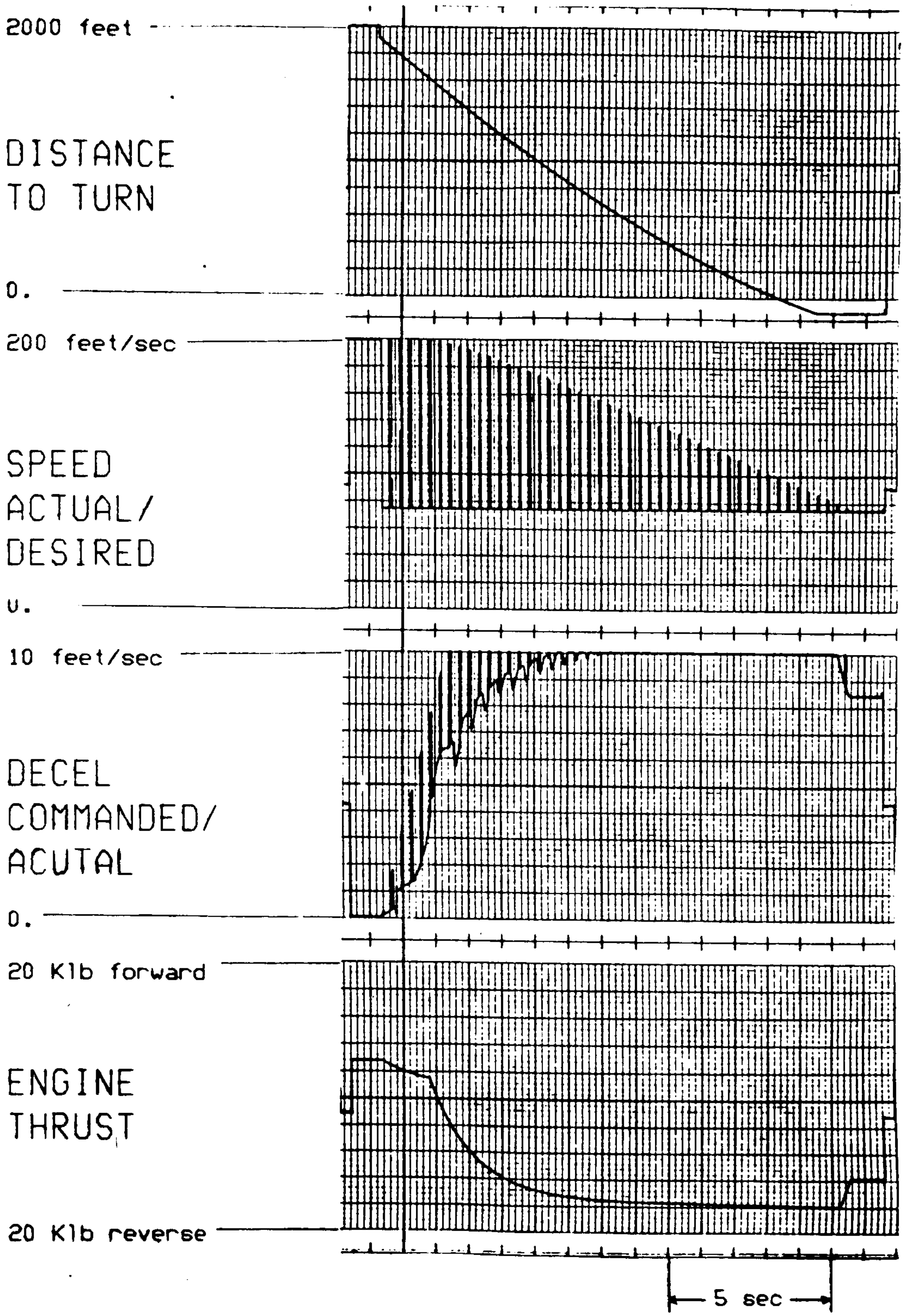

FIGURE 22 (cont'd): TIME HISTORY DATA, RUN # 204

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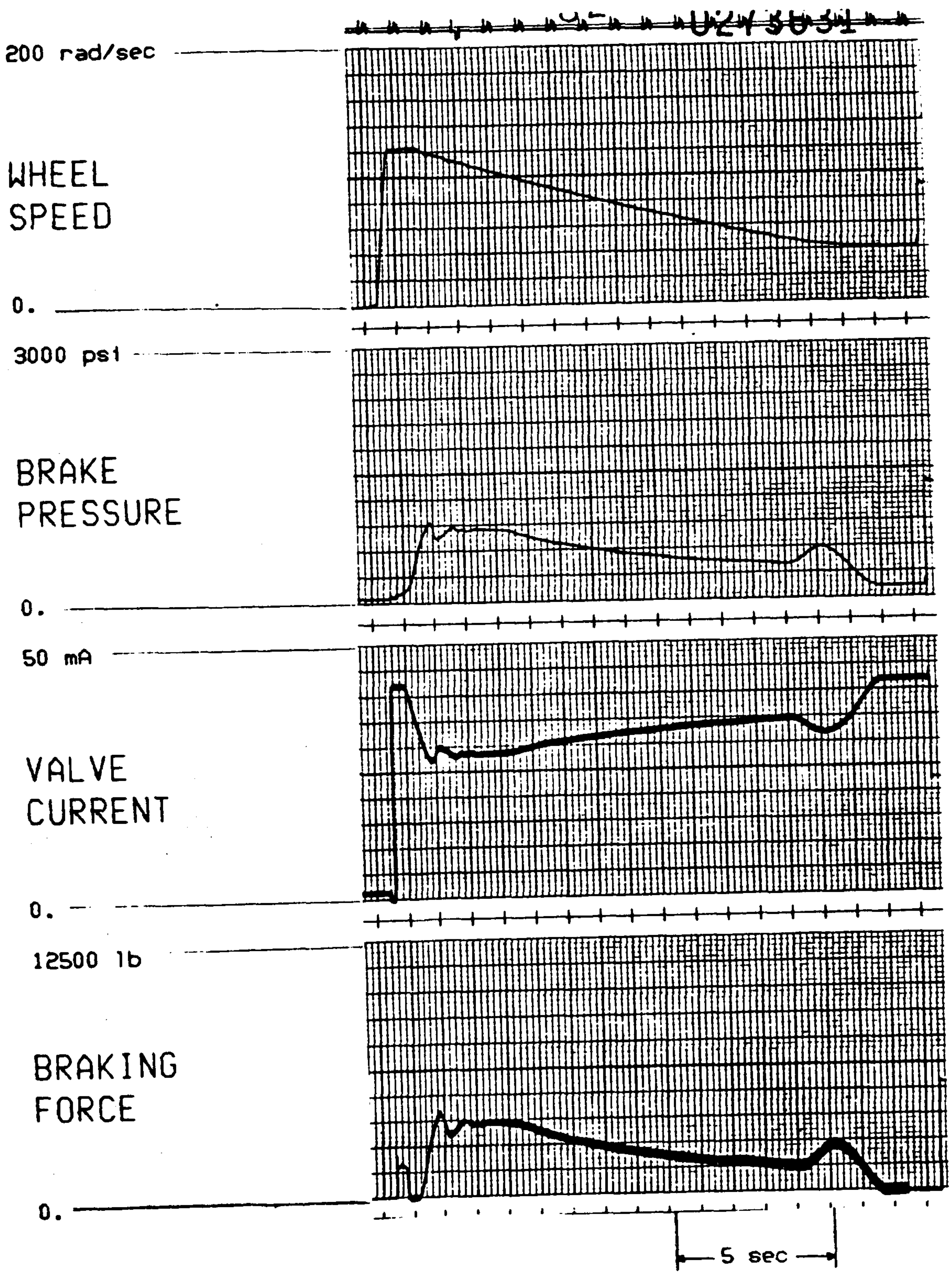

FIGURE 23 : TIME HISTORY DATA, RUN # 304

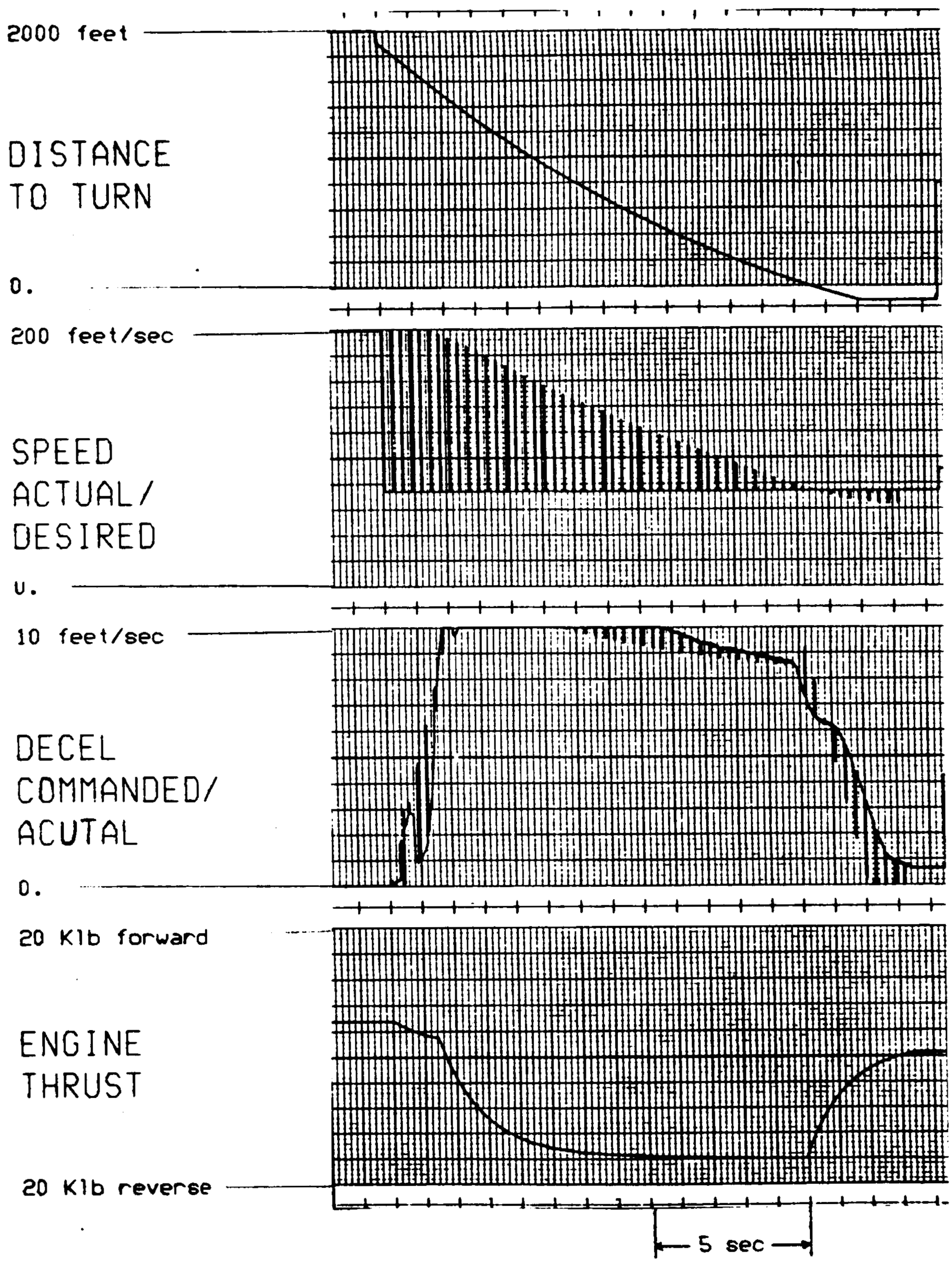

FIGURE 23 (cont'd): TIME HISTORY DATA, RUN # 304

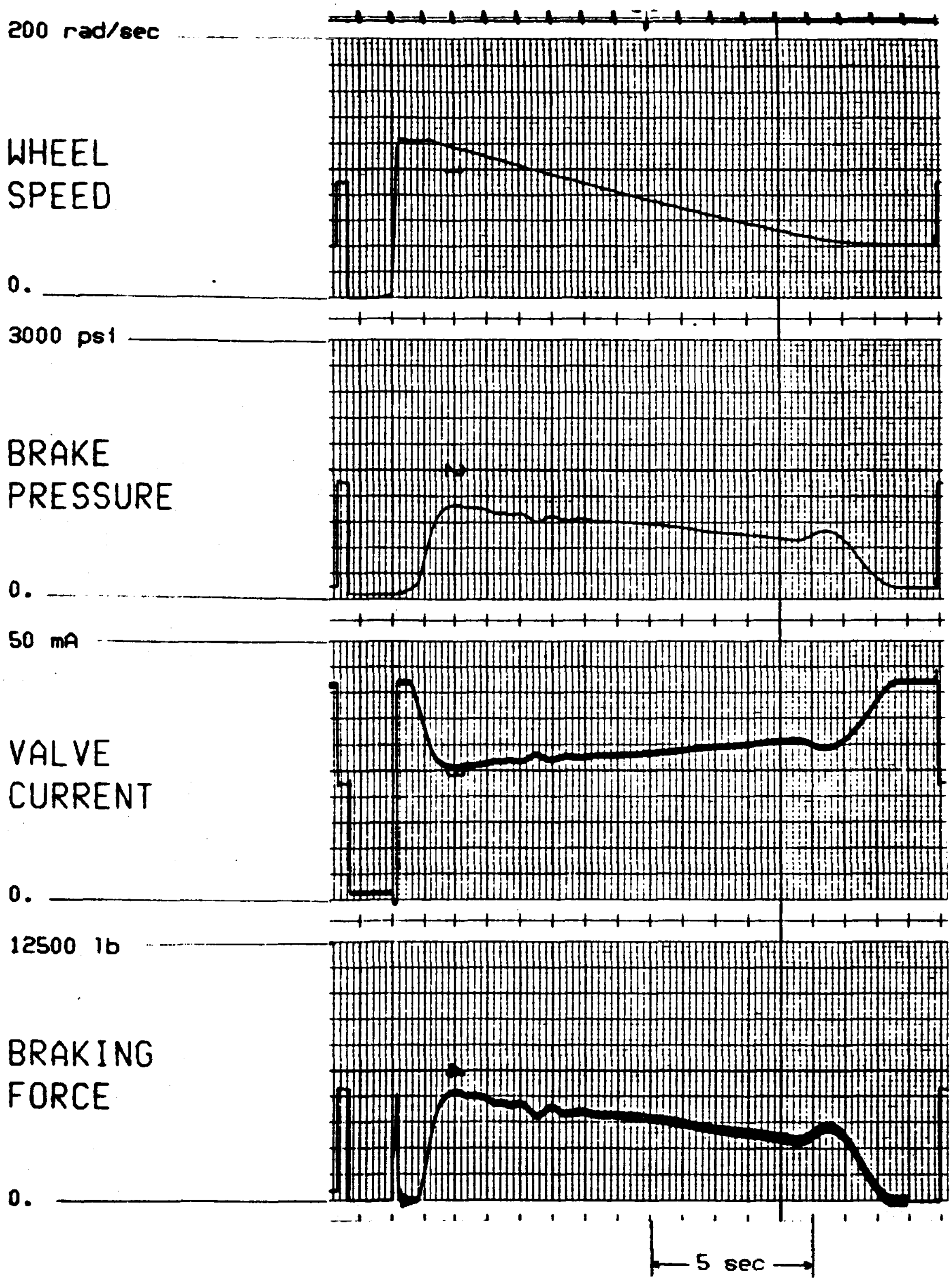

FIGURE 24 : TIME HISTORY DATA, RUN # 404

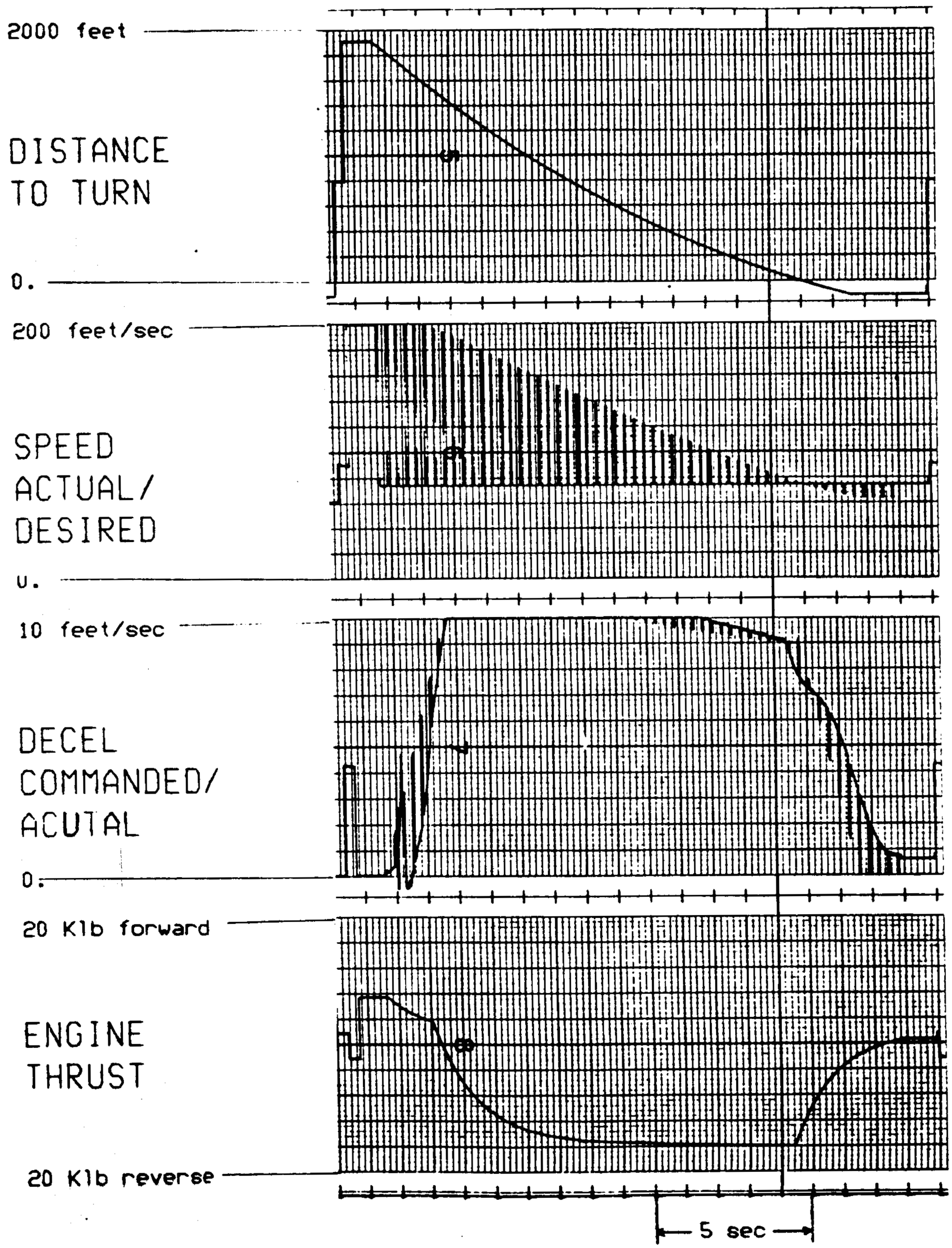

FIGURE 24 (cont'd): TIME HISTORY DATA. RUN # 404

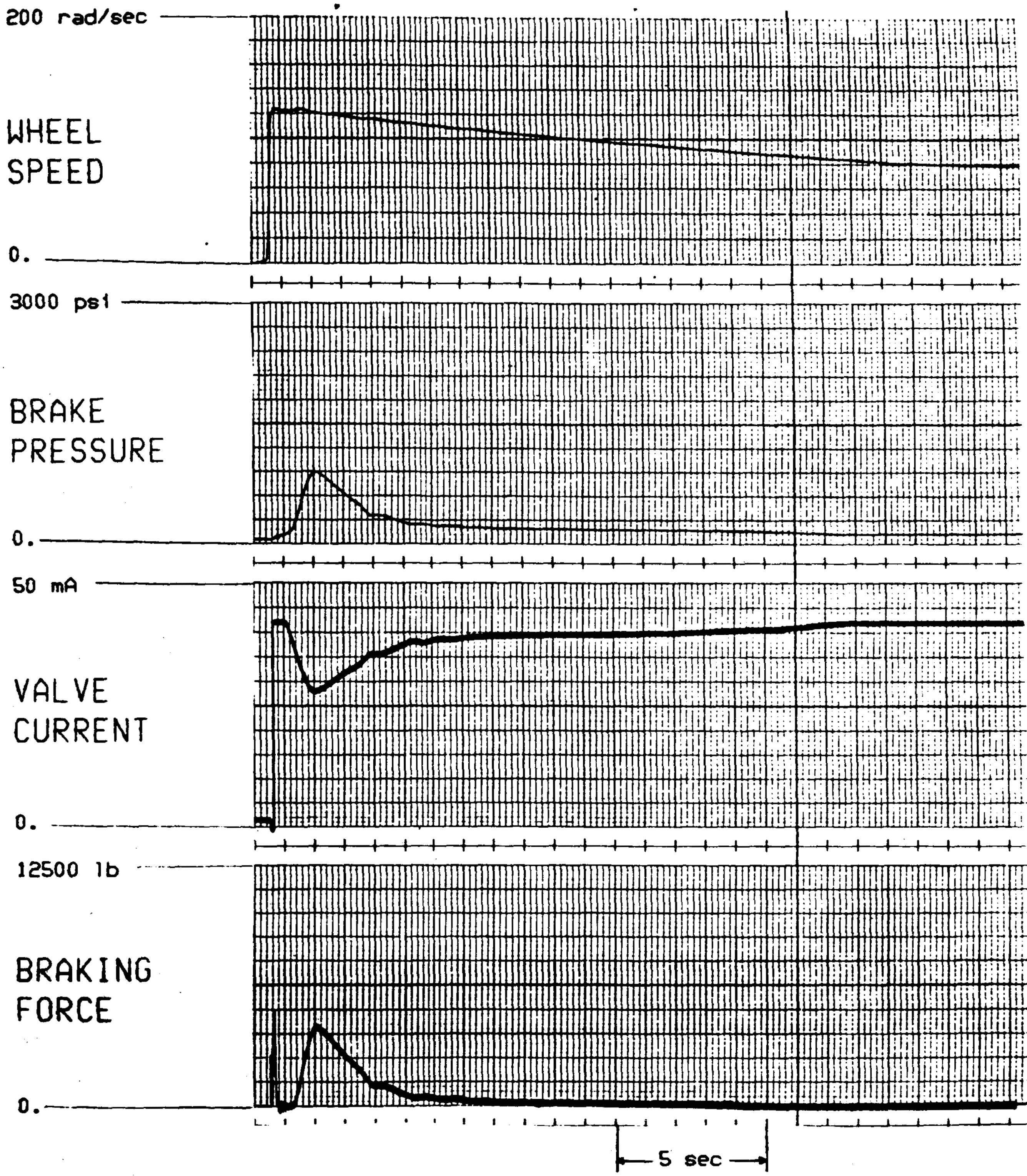

FIGURE 25 : TIME HISTORY DATA, RUN #409

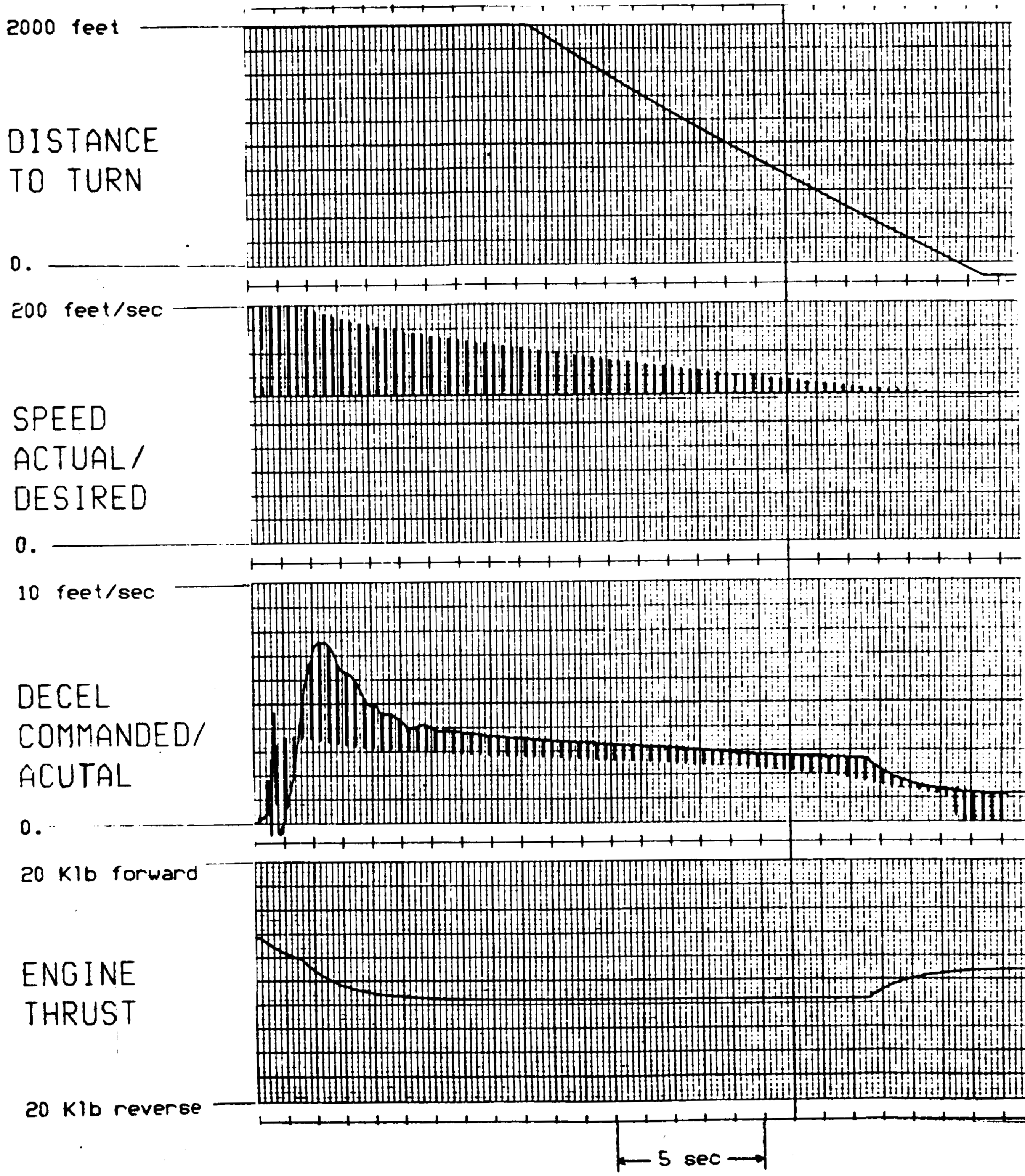

FIGURE 25 (cont'd): TIME HISTORY DATA, RUN #409

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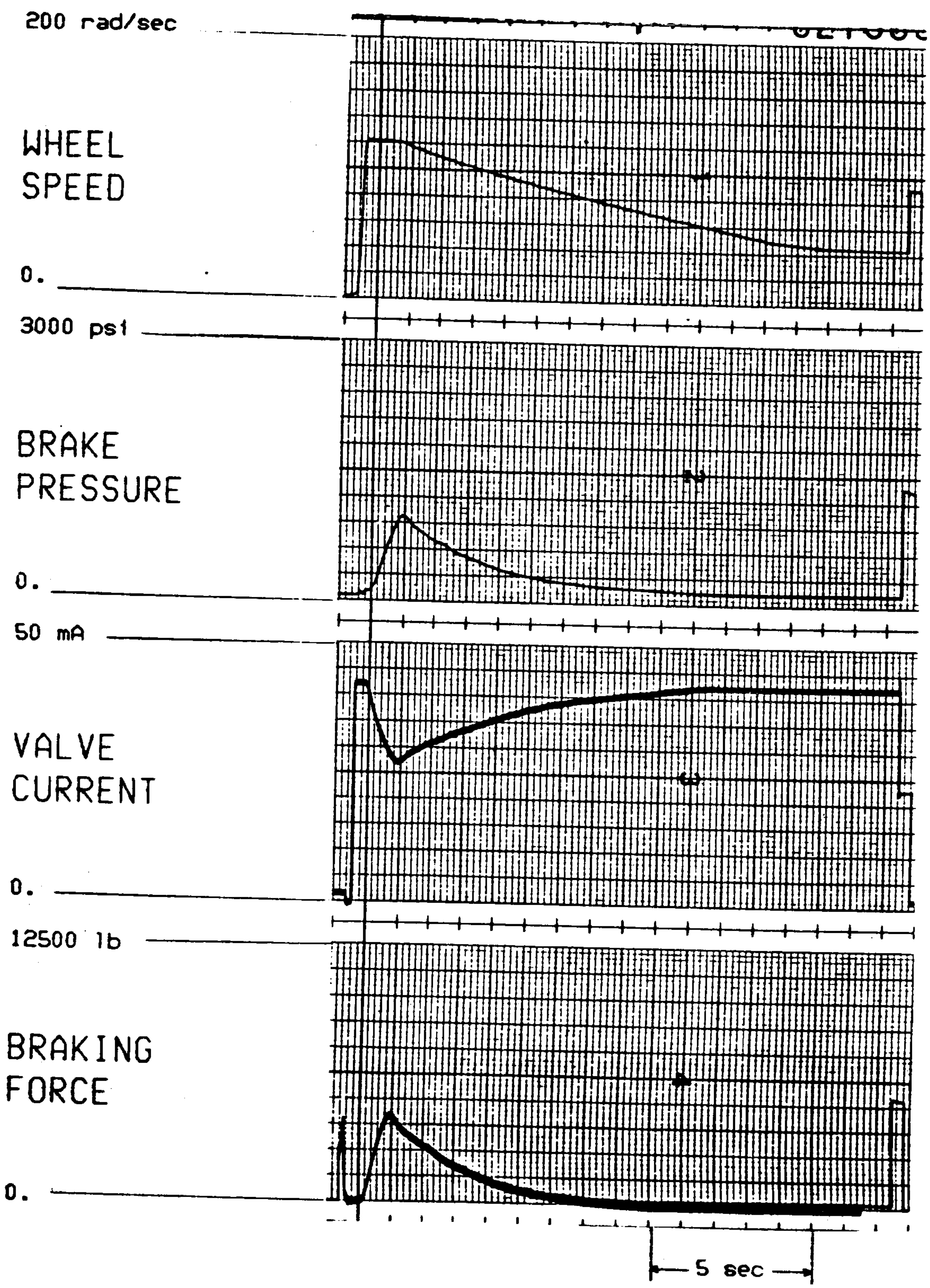

FIGURE 26 : TIME HISTORY DATA, RUN # 504

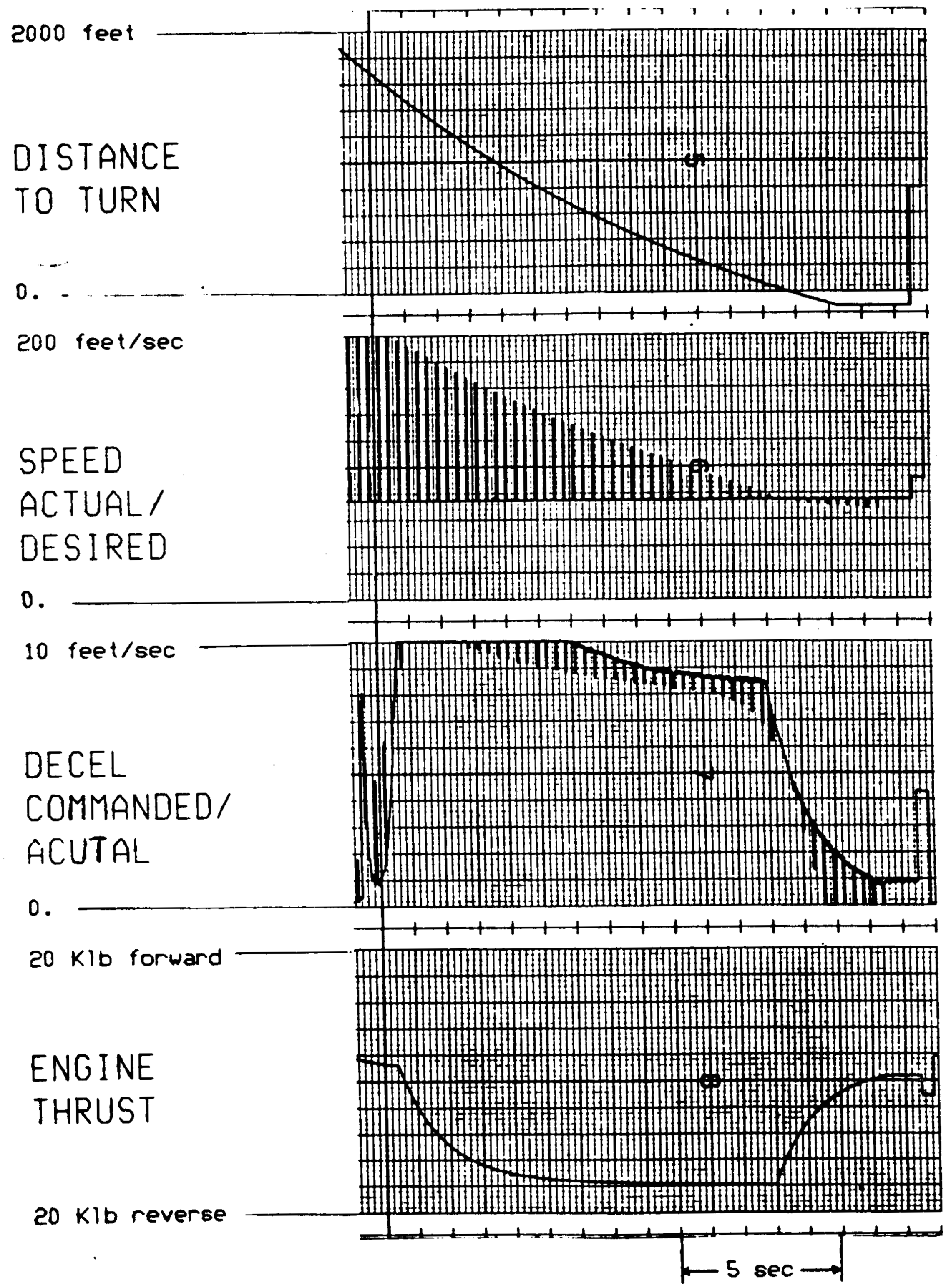

FIGURE 26 (cont'd): TIME HISTORY DATA, RUN #504

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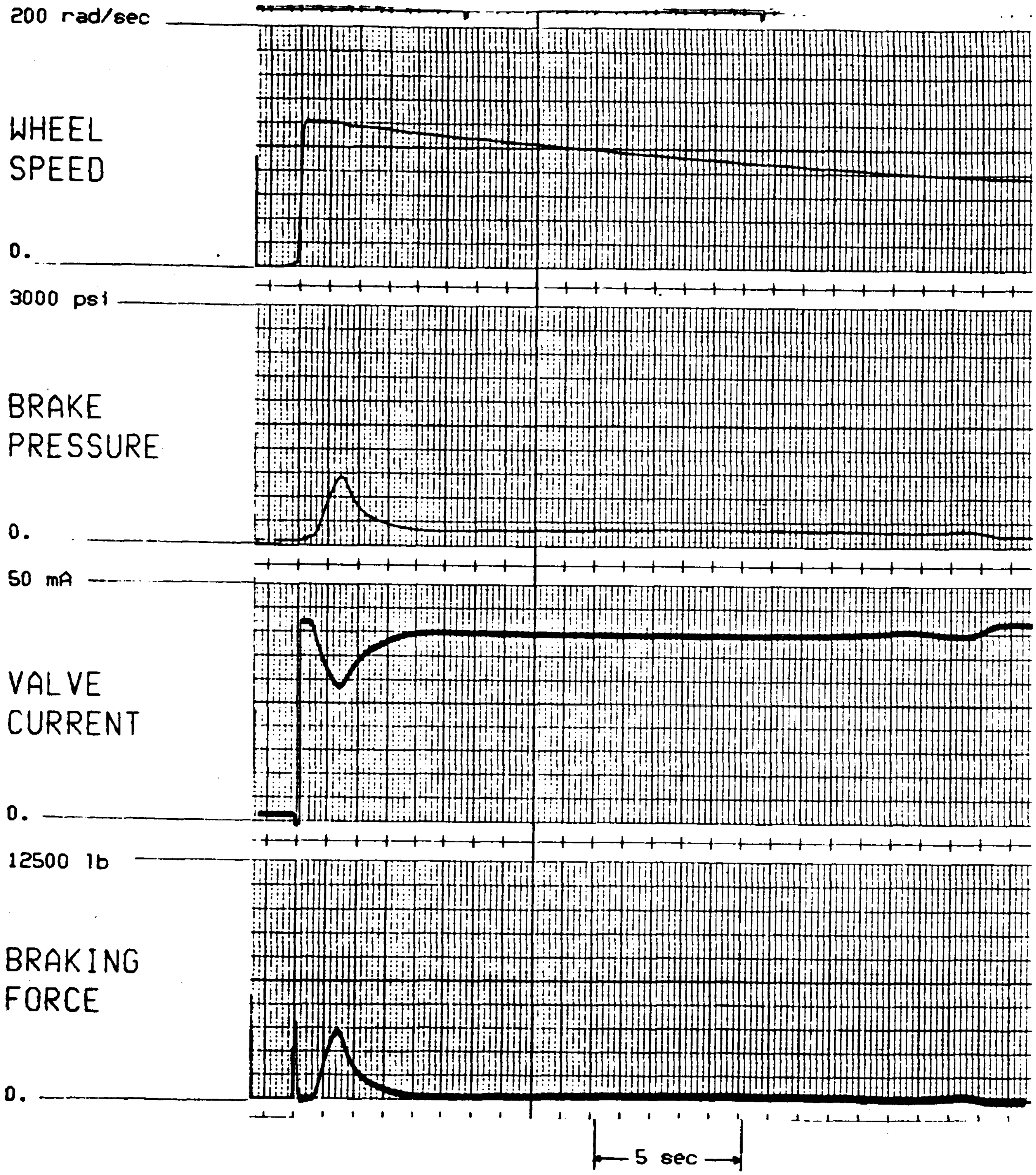

FIGURE 27 : TIME HISTORY DATA, RUN # 509

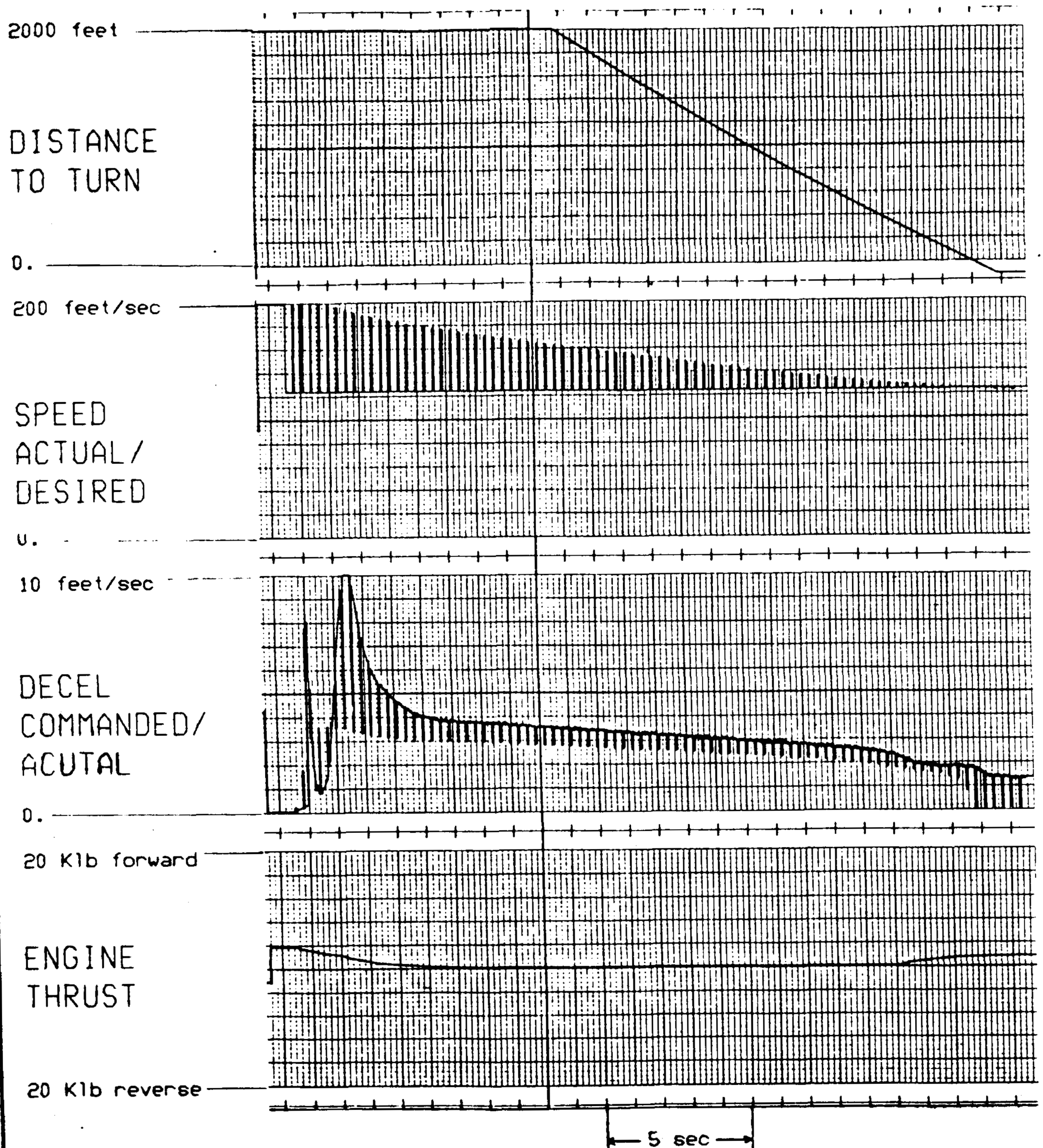

FIGURE 27 (cont'd): TIME HISTORY DATA, RUN #509

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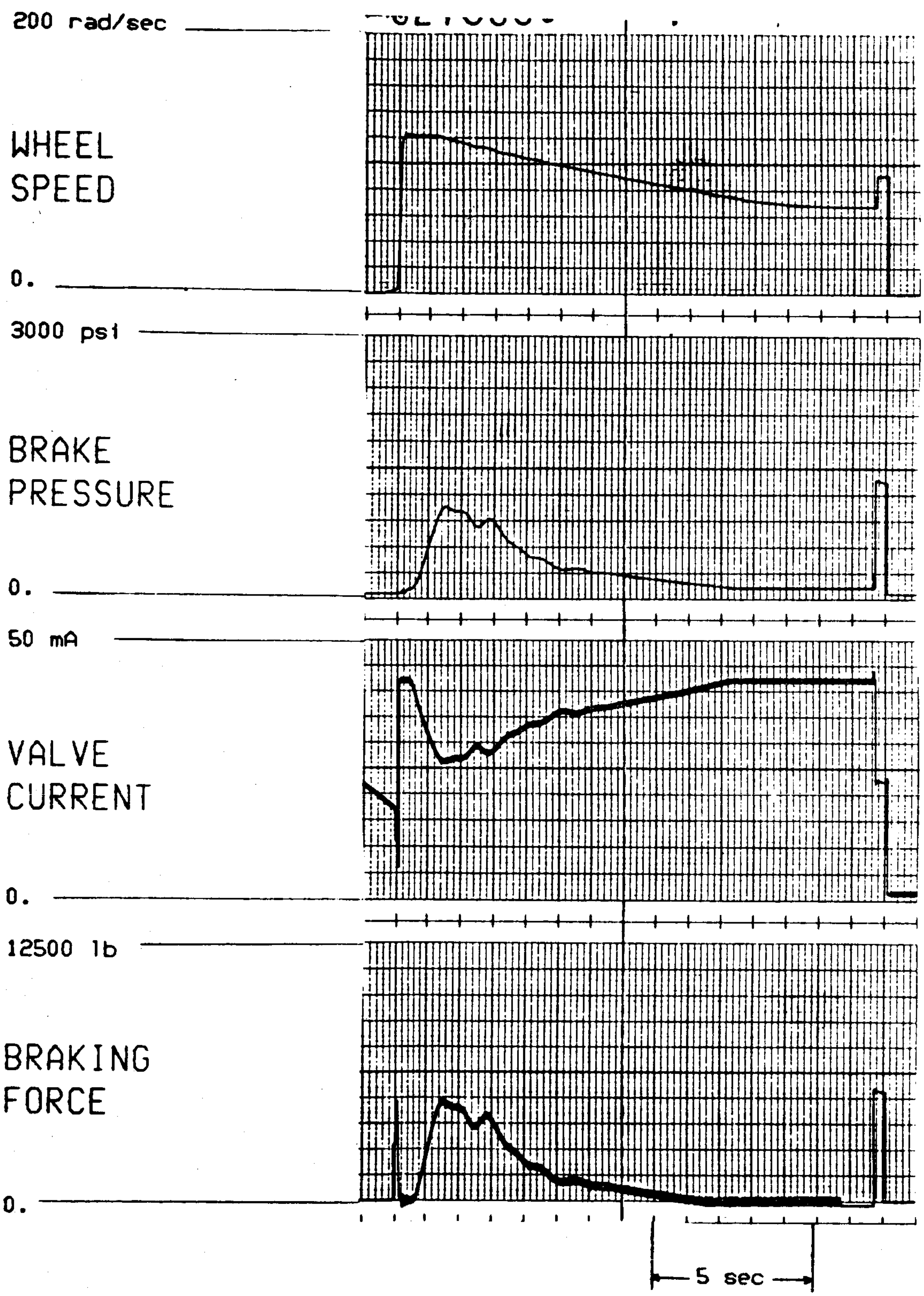

FIGURE 28 : TIME HISTORY DATA, RUN # 601

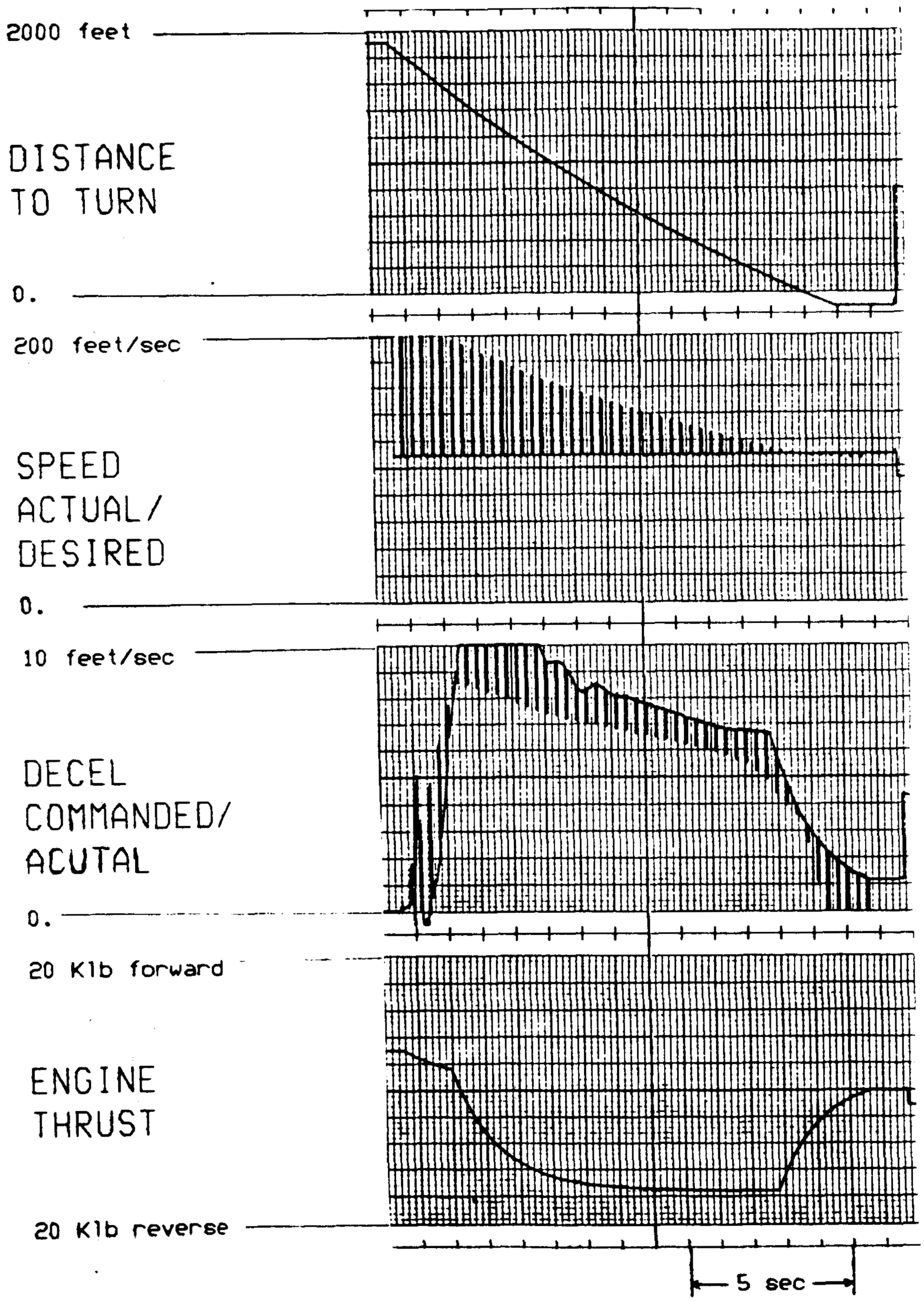

FIGURE 28 (cont'd): TIME HISTORY DATA, RUN #601

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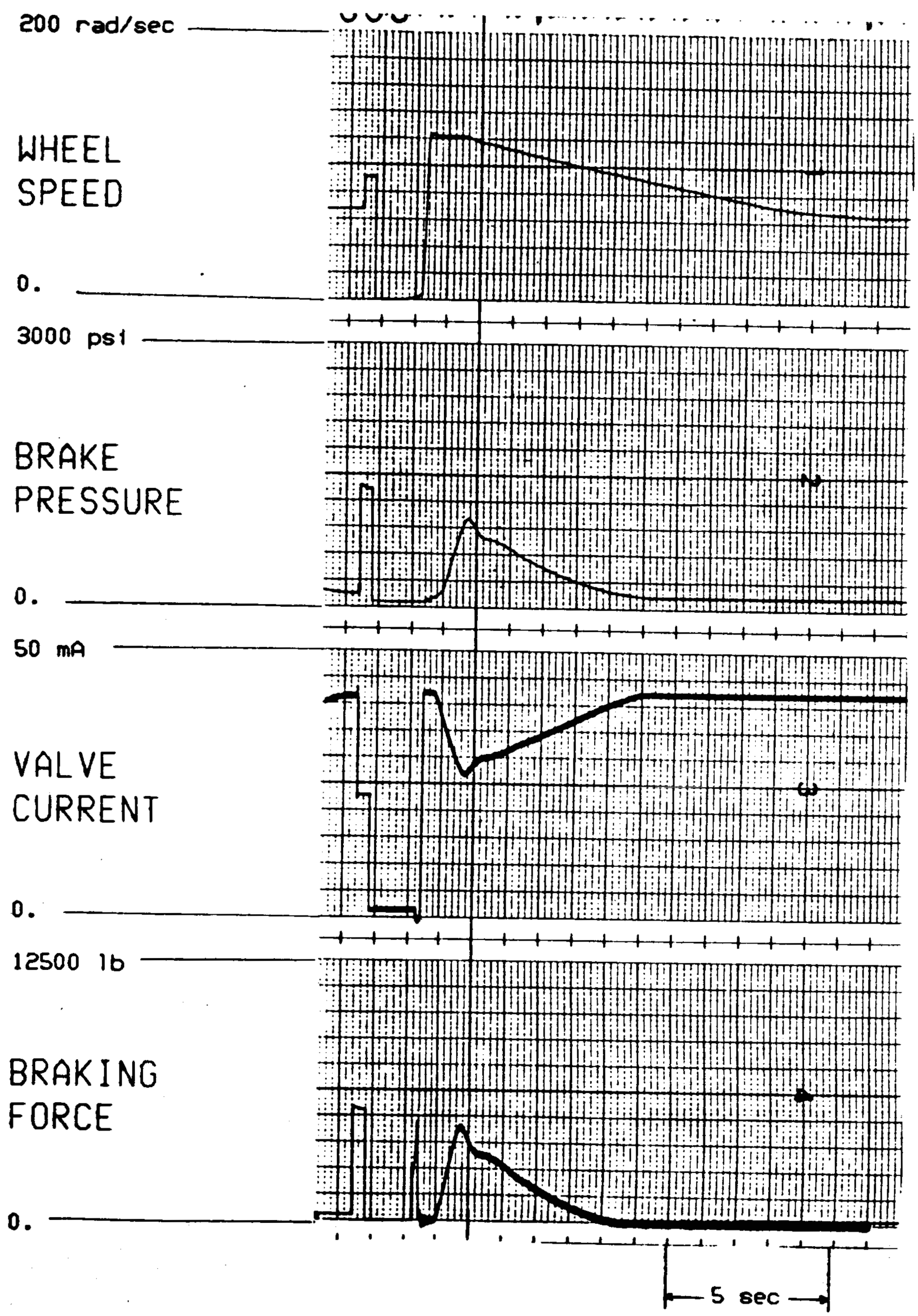

FIGURE 29 : TIME HISTORY DATA, RUN # 701

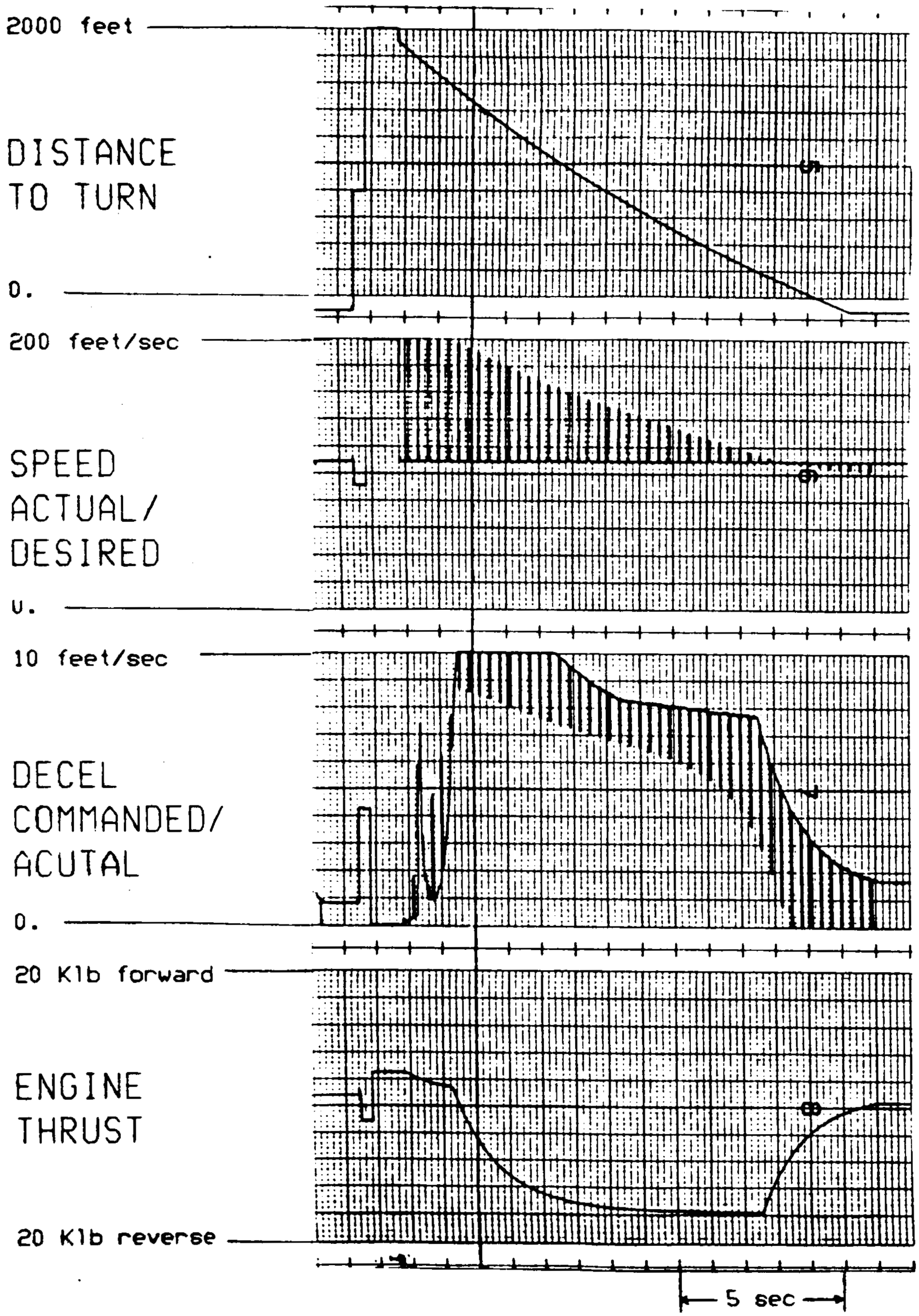

FIGURE 29 (cont'd): TIME HISTORY DATA, RUN # 701

5.0 CONCLUSIONS

The modifications designed under this contract and presented in this report will enable the research flight control computer to control deceleration during landing roll-out in such a way as to bring the aircraft to a desired speed at a particular spot on the runway for the purpose executing automatic, high speed turn-offs.

The required modifications are summarized as follows:

ARMING LOGIC

Add a new setting (VAR for variable, in addition to the current OFF, MIN, MED, MAX settings) to the autobrake control switch in the forward flight deck, and a relay for safety logic.

DECELERATION CONTROL

Modify the selected deceleration control cards in the anti-skid box to respond to the continuously variable deceleration command.

AFT FLIGHT DECK AND INTERFACE

Add the VAR setting to the autobrake control switch and add a corresponding channel to the communication network between aft and forward flight decks.

Two aspects of the performance of the proposed continuously variable decleration control system must be emphasized. Due to the time response of the deceleration control loop, it takes two seconds to release the brakes after the deceleration command goes to zero. To avoid braking during the turn-off, it is recommended that algorithm used to compute the deceleration command take account of this delay. Secondly, the system does not provide very precise deceleration control. The discrepancy between the command and the actual deceleration will often exeed 1 foot/sec/sec. However, the system implemented in these simulated tests does provide the desired results in terms of speed and distance.

REFERENCES

(1) Pines, S., "Terminal Area Automatic Navigation, Guidance, and Control Research Using the Microwave Landing System (MLS)", NASA CR-3451, August, 1981.

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15. Supplementary Notes
Langley Technical Monitor: James C. Young
Final Report - Task 7

16. Abstract
Modifications were designed for the B-737-100 Research Aircraft autobrake system hardware of the Advanced Transport Operating Systems (ATOPS) Program at Langley Research Center. These modifications will allow the on-board flight control computer to control the aircraft deceleration after landing to a continuously variable level for the purpose of executing automatic high speed turn-offs from the runway. A bread board version of the proposed modifications was built and tested in simulated stopping conditions. Test results, for various aircraft weights, turnoff speed, winds, and runway conditions show that the turnoff speeds are achieved generally with errors less than 1 ft/sec.

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